REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
15 Dec 97

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE
SEE SYMPHONY AUTOMATED IDENTIFICATION AND VISUALIZATION OF EMOTIONS IN MUSIC

5. FUNDING NUMBERS

6. AUTHOR(S)
John Robert Billups IV

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Colorado at Colorado Springs

8. PERFORMING ORGANIZATION REPORT NUMBER
97-147

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
THE DEPARTMENT OF THE AIR FORCE
AFIT/CI, BLDG 125
2950 P STREET
WPAFB OH 45433

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Unlimited Distribution
In Accordance With AFI 35-205/AFIT Sup 1

12b. DISTRIBUTION CODE

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

13. ABSTRACT *(Maximum 200 words)*

19971230 158

DTIC QUALITY INSPECTED 2

14. SUBJECT TERMS

15. NUMBER OF PAGES
101

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT

18. SECURITY CLASSIFICATION OF THIS PAGE

19. SECURITY CLASSIFICATION OF ABSTRACT

20. LIMITATION OF ABSTRACT

SEE SYMPHONY

AUTOMATED IDENTIFICATION AND VISUALIZATION OF EMOTIONS IN MUSIC

by

John Robert Billups IV

B.A., Hawaii Pacific University, 1990

A Thesis submitted to the Graduate Faculty of the

University of Colorado at Colorado Springs

in partial fulfillment of the requirements for the degree of

Master of Science

Department of Computer Science

1997

This thesis for the Master of Science Degree by

John Robert Billups IV

has been approved for the

Department of Computer Science

by

Alan M. Davis, Chair

Julia Hoerner

Lewis J. Pinson

Frederick T. Sheldon

Curtis F. Smith

11/25/97

Date

To my son, Noel.
My inspiration for so many things.

CONTENTS

CHAPTER

1. INTRODUCTION...1

    Hypothesis...2

    Arrangement of the Thesis...2

2. LITERATURE SURVEY...4

    Properties of Music...4

        Pitch...5

        Timbre...5

        Intensity...6

        Duration...6

    Music and Emotion...7

        Pitch...8

        Intensity...9

        Duration...9

        Relationship of Pitch, Intensity, and Duration...10

    Instruments and Pitch...11

    Psychology of Color...15

    Deafness...17

Eye Music.. 18

Skin Music..20

Previous Related Research..21

Color and Music Association..21

Color Response to Music..21

Environmaent or Innate...22

Manually Generated Visual Music... 25

Predetermined Animations...25

Fantasia..26

Automatically Generated Visual Music..28

Automatically Generated Animations..28

Screen Dance..30

3. METHOD..33

Instrument..33

Music...34

Music to Emotion to Animation..35

Identifying Emotion in Music...35

Portraying Emotion with Colors...39

Object Shape and Movement..40

Putting it Together...42

Software - See Symphony...43

Design..43

Challenges 46

Customizing 47

Running See Symphony 49

Testing 50

Phase I 50

Phase II 52

4. RESULTS 54

Questionnaire Results 54

Hearing Impaired Results 54

Hearing Results 56

Discussion 58

Color-Emotion Association 59

Responses to Animation 60

General Observations 61

Group Reactions 65

Discussion 65

5. CONCLUSIONS AND FURTHER RESEARCH 68

Conclusions 68

Further Research 69

REFERENCES 71

APPENDIX

A. DESCRIPTION OF THESIS FOR QUESTIONNAIRE 73

B. COVER LETTER AND QUESTIONNAIRE FOR HEARING IMPAIRED SUBJECTS IN RESEARCH STUDY 75

C. COVER LETTER AND QUESTIONNAIRE FOR HEARING SUBJECTS IN RESEARCH STUDY 80

D. MESSAGES FROM GROUP SUBJECTS 85

FIGURES

Figure

2.1 Instrument Frequency Ranges ... 12

2.2 Adjusted Instrument Frequency Ranges ... 14

2.3 Spectrograph ... 15

2.4 Animation Terminals ... 30

2.5 ScreenDance Dancer ... 31

3.1 Pitch Shapes ... 41

3.2 Disjunct Pitch Shapes ... 41

3.3 Volume Size ... 42

3.4 See Symphony Data Flow - Level 1 ... 44

3.5 Decomposition of "Extract Data" Process - Level 2 ... 45

3.6 Decomposition of "Analyze Data" Process - Level 2 ... 46

3.7 Customize Control Panel ... 48

3.8 Individual Presentation Layout ... 52

3.9 Group Presentation Layout ... 53

4.1 False Fast Tempo Identification ... 62

4.2 False Slow Tempo Identification ... 63

4.3 Display Simulation ... 66

TABLES

Table

2.1 Musical Characteristics for Producing Various Emotional Expressions 11

2.2 Frequencies of Notes 13

2.3 Color and Emotion Associations 17

2.4 Predominant Color Choice 23

3.1 Emotional Expressions Related to Musical Elements for Violin 37

3.2 Emotion of Music to Color 40

3.3 Default Color to Emotion Association 48

3.4 Customization Parameters 49

4.1 Responses to Questionnaire (Hearing Impaired) 55

4.2 Color Selection (Hearing Impaired) 55

4.3 Responses to Music/Animation (Hearing Impaired) 56

4.4 Responses to Questionnaire (Hearing) 57

4.5 Color Selection (Hearing) 57

4.6 Responses to Music/Animation (Hearing) 58

CHAPTER 1

INTRODUCTION

Music can portray a wide range of feelings and emotions. Music can be happy or it can be melancholy. Music can be threatening, energetic, or easy going. For those of us that can hear, music is a wonderful medium. Unfortunately, there is a subset of our population who are not able to enjoy music as it was meant to be enjoyed. The form in which music is currently presented deprives the hearing impaired of the experience that so many of us take for granted. The question to be asked is whether music can be similarly appreciated via other senses besides hearing. Is there a way to portray an emotional qualities of music for those without hearing?

In today's multimedia society, graphics, images, and video commonly accompany music as a way to enhance the experience. These images can emphasize a feeling or emotion that is already present in the music. Conversely, the same images viewed by themselves would probably not portray a similar emotion.

Music can be broken down into four basic properties: pitch, timbre, intensity, and duration (Christ et al, 1980). The characteristics of these four properties determine the mood or emotion of the music (Politoske, 1979). For a visual medium to mirror the aural nature of music the four properties must be reflected.

Today, the computer is a common part of everyday life in many ways. Computers can read, play, and analyze music. Computers can also generate impressive graphics. Putting these two attributes together will enable computers to automatically detect and translate the aural properties of music into visual properties.

Simply stated, the emotions of music can be automatically identified and displayed visually in an animated fashion using color, shape, and movement. Since music is a complex medium this work will concentrate on solo violin compositions.

Music is deeply embedded into our culture and in many other cultures of the world. By providing an additional medium, those who can not hear music could see music and therefore achieve a broader experience in everyday life.

Hypothesis

It is possible to automatically identify the emotions portrayed by music and display those same emotions visually through the use of computer hardware and software.

Arrangement of the Thesis

This thesis deals with a wide range of topics. Most of the areas are not computer science related, but they must be covered as a foundation for the work that is accomplished in this thesis and for the work that will follow.

Chapter 2 is the literature review of topics relevant to this thesis. These topics include: properties of music, music and emotion, instruments and pitch, psychology of color, deafness, and previously related work in the field of manually and automatically generated visual music. Chapter 3 deals with the method used to show that the

hypothesis is possible. Chapter 3 covers the following: instrument and music used, translation from music to emotion to animation, and software implementation. The software section of Chapter 3 also describes how the software was tested with deaf and hearing individuals. The results of the methods are detailed in Chapter 4. Conclusions and suggestions for further research are discussed in Chapter 5. Appendices A, B, and C contain descriptions, cover letters, and questionnaires used in the testing of the software with deaf and hearing subjects. Appendix D contains messages from six hearing subjects involved in the testing of the software.

CHAPTER 2

LITERATURE REVIEW

This work crosses multiple disciplines and areas: properties of music, music and emotion, psychology of color, deafness, and software engineering. I researched each area thoroughly enough to gain the knowledge necessary to achieve my goal of translating the emotion of music to color, shape, and movement.

Properties of Music

Musical sound can be broken down into four basic properties: pitch (frequency), timbre (tone quality), intensity (loudness), and duration (length of time note is held) (Christ et al, 1980). Pitch ranges from high to low. Intensity ranges from loud to soft. Duration ranges from long to short. Timbre, the characteristic of the sound, depends on the instrument being played. All four properties can be measured and analyzed.

Music contains many more properties and elements than those I have listed, such as melody, rhythm, harmony and accent to name a few. From my readings it appears to me that music's other characteristics can be broken down into the previously mentioned four basic properties.

Pitch

The number of vibrations per second determines the pitch of a given musical tone (Politoske, 1979). The faster the vibrations the higher the pitch. The human ear, on average, can hear frequencies between 20 and 20,000 cycles per second (cps) (Culver, 1956).

From note to note over a short term there are a finite number of ways that the pitch can change. The pitch can remain steady, go higher, go lower, or alternate. If the pitch rises continually then it is ascending. If the reverse is true then it is descending. If there is a large distance between consecutive pitches then they are disjunct; if the distance is small they are conjunct (Politoske, 1979). When two or more frequencies are invoked simultaneously and produce an unpleasant sound it is said to be dissonant; if the effect is pleasing it is consonant (Culver,1956). The direction in which the pitch travels has a major impact on which emotions are being expressed in the music.

Timbre

The timbre of the music is simply the quality of the music (Culver,1956). Timbre is what lets us distinguish between instruments. Each instrument has its own voice; they each have their own particular sound. For example, we can distinguish between a string instrument and a woodwind instrument playing the same note at the same intensity level.

At this point in my work, timbre will not be much of a factor since I will be focusing on one instrument.

Intensity

Intensity is the loudness of the music. A change in volume can occur quickly or slowly depending on the effect that is desired. As with pitch there are a finite number of things that can happen with the volume in a musical piece from note to note. The volume can remain steady, increase, decrease, or alternate.

In relation to hearing, the intensity level of a given sound must change by one decibel (26%) before the human ear can detect a change in the strength of that sound (Culver,1956).

In musical works the level of loudness has been classified into following categories: very soft, soft, moderately soft, moderately loud, loud, very loud, sudden stress on a single note, and loud followed suddenly by soft (Politoske, 1979).

Again, as with pitch, the direction and level of the volume has major impact on which emotions are being expressed in the music.

Duration

Duration is the length of time that a note is held. Different durations are specified as follows: whole, half, quarter, eighth, sixteenth, thirty-second, and sixty-fourth (Politoske, 1979). The actual length or number of beats that each duration represents depends on how many beats a whole note represents. If a whole note is four beats then each subsequent duration is the given fraction of the whole note. For example, in this case a quarter note would be one beat.

The duration of silence, the length of time between notes, is also an important factor. The combination of duration of note and silence (which may be none) make up the tempo of the music.

As with pitch and intensity, the duration from note to note can either remain constant, become shorter, become longer, or alternate.

It should be obvious here that the time that a note is held also has a significant impact on the feeling of the music.

Music and Emotion

> "Those who appreciate music do not listen passively and passionlessly. They actively listen for what is to come in light of what has been foretold, pointed ahead by the unfolding progressions (Goldman, 1995)"

Each of the three elements, pitch, intensity, duration contribute to emotions and feelings portrayed by music. While each has its influence, it is most often not a factor of just one of the properties. It is more likely a combination of two or more that brings music to life.

It should be noted here that there are two major camps regarding music and emotion: cognitivist and emotivist (Radford, 1989). Cognitivists believe that music may express various emotions such as sadness, fear, anger, happiness, etc., and that we can identify these emotions in music. They claim that listening to, for example, sad music does not, in turn, make us sad. On the other hand, emotivists say that if the music is sad then it may make us feel so. Emotivists argue that if the music does not move you to a certain emotion than the music should not be labeled as such. I will not get involved in that argument. I'm making the assumption that music does portray and invoke emotions.

What I'm most interested in is the portrayal of emotions in music. There is greater agreement on what emotions music portrays than on what emotions music evokes (Storr, 1992). The mood of the individual or the occasion are just two factors which may affect a person's reaction to the same piece of music (Storr, 1992).

Another point of interest is that the degree to which music affects us depends a great deal on how we perceive it. The difference comes from whether we hear music or listen to music (Cook, 1990). The difference is how much attention is paid to the music. I think it is simple to agree that a piece of music played in a concert hall or in one's living room while relaxing (listening) has a much more profound effect on ones emotions than does the same music being played as background music in a shopping mall (hearing). When I discuss the emotions in music I am referring to listening as opposed to just hearing the music.

The emotional impact of each element will be described below, followed by a discussion of the effect of the elements combined.

Pitch

Pitch, by itself, is strongly linked to perceived emotions (Bruner, 1990). The higher the pitch the more exciting or happy the music seems to become. On the other hand, a low pitch seems to represent sadness.

Pitch can also be thought of movement in spatial terms. Ascending pitches produce a feeling of expansion, excitement, or upward movement; descending pitches give the feeling of falling or a downward pull that may be associated with rest, or finality (Politoske, 1979). An alternating trend in pitch would give the feeling of moving up and

down. The height and depth of the movements would greatly depend on whether the pitches are conjunct or disjunct and the length of ascent and descent.

Disjunct tunes are more likely to be dramatic, energetic, and agitated, while conjunct tunes are sweeter, playful, happy and more lyrical (Bruner, 1990; Politoske, 1979). The same can be said for dissonant and consonant sounds, respectively.

Intensity

Intensity has a definite link to the mood of a musical piece. Loud music is animated, triumphant, or exciting, while softer music is characterized as delicate, tranquil, peaceful, or serious (Bruner, 1990). It is clear that the amount of volume can be related to the amount of energy that the musical piece is portraying. The louder a piece the more energy the piece portrays to the listener.

Duration

I did not find much written about duration and its direct relation to emotions. However, there is information on tempo of music. As discussed previously, tempo is simply a combination of durations of notes and silence. For example, a musical piece with short duration on notes and silence would represent a quick tempo. If the duration of either were increased the tempo would decrease.

Looking at how tempo portrays emotions it seems almost natural to imply that a quick tempo represents quickening, excitement, or activity (Politoske, 1979). It is equally natural to suggest that a slow tempo can be sad, serious, or serene (Bruner, 1990).

Relationship of Pitch, Intensity, and Duration

Each of the three properties (pitch, intensity, and emotion) have emotional implications of their own, but individually they do not make up a whole emotion. The true effect comes when they are combined.

An interesting observation discussed by Goldman (1995) is that the main basis for our recognition of pitch, intensity, and duration in music is due to their resemblance of natural human expressions of emotion by voice, demeanor, and behavior. He goes on to say, if we accept a spatial description of notes then we can also describe it's movement which, can then be compared to human movements and natural expressions of emotion.

Let's apply this thinking to some common emotional states. When one is sad, movements tend to be slower; the voice is lower, softer, and drawn out. Even cries of sadness (in Western culture) are typically low in volume and lacking in energy. This fits what was previously described as sad with the three properties, the pitch is low, intensity is low, and duration is long.

When one is happy, movements are quicker, the voice is higher, faster, louder, and full of energy. Laughter is a good example of these attributes. Happy music has the same general properties: high pitch, fast tempo, medium intensity.

Table 2.1 list a compilation of musical elements and their relation in portraying different emotions.

Table 2.1 Musical Characteristics for Producing Various Emotional Expressions

Musical Element	Serious	Sad	**Emotional** Serene	**Expression** Happy	Exciting	Frightening
Mode	Major	Minor	Major	Major	Major	Minor
Tempo	Slow	Slow	Slow	Fast	Fast	Slow
Pitch	Low	Low	Medium	High	Medium	Low
Rhythm	Firm	Firm	Flowing	Flowing	Uneven	Uneven
Harmony	Consonant	Dissonant	Consonant	Consonant	Dissonant	Dissonant
Volume	Medium	Soft	Soft	Medium	Loud	Varied

Source: Data from Gordon Bruner, "Music, Mood, and Marketing." *Journal of Marketing* 54, no. 4 (1990): 100.

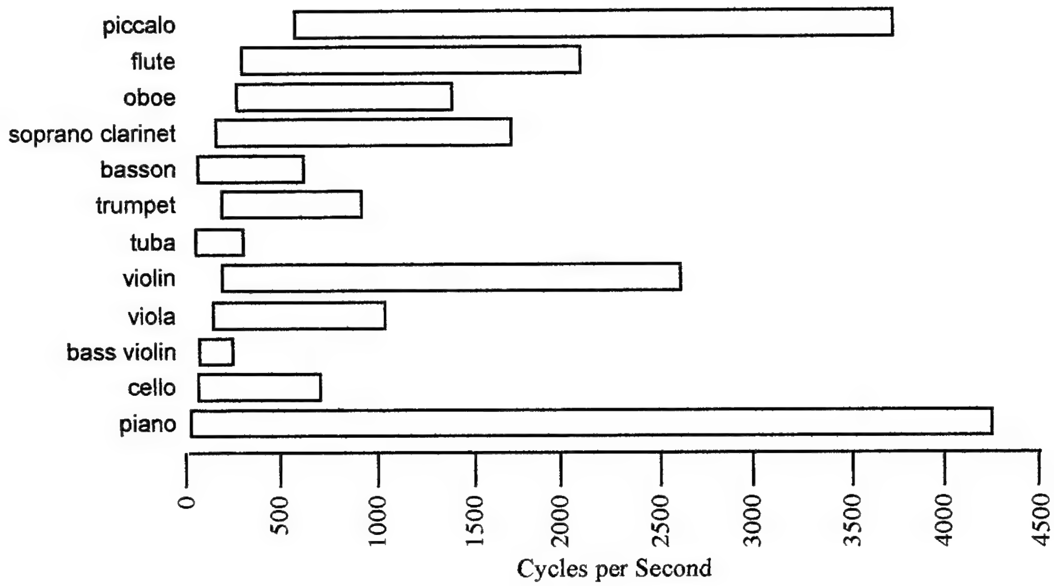
As can be seen, to accurately determine the feelings that a piece of music is portraying its imperative to examine multiple properties simultaneously. While individual elements of music do have emotional connotations, they do not by themselves tell the whole story.

Instruments and Pitch

A healthy human ear can hear sounds that are in the range of 20 to 20,000cps. The frequency range produced by musical instruments is approximately 27 to 4200cps (Backus, 1977). Figure 2.1 displays the frequency ranges of some popular musical instruments.

The piano is the only instrument listed that can obtain the full spectrum of frequencies that can be produced by musical instruments. It is clear that the piano can reach all notes from high to low. The other instruments listed can only obtain a subset of the frequency range.

Figure 2.1 Instrument Frequency Ranges



Sources: Data from Backus, John. *The Acoustical Foundations of Music.* New York: W. W. Norton & Company, 1977; White, Harvey and Donald White. *Physics and Music - The Science of Musical Sound.* Philadelphia: Saunders College, 1980; and Culver, Charles. *Musical Acoustics,* 4th ed. New York: McGraw Hill, 1956.

What is the definition of a high, medium, or low pitch? The International Standards Organization recommended, in 1953, that 440cps be used as the standard frequency for music worldwide (White and White 1980). Today, this is what most musicians in symphony orchestras use to tune their instruments.

Examining Figure 2.1, most of the instruments have 440cps within their frequency ranges. More specifically, the violin's frequency range is approximately 170 to 3000cps. Since 440cps is the standard, can we consider it to be the medium pitch for orchestral music?

Table 2.2 Frequencies of Notes

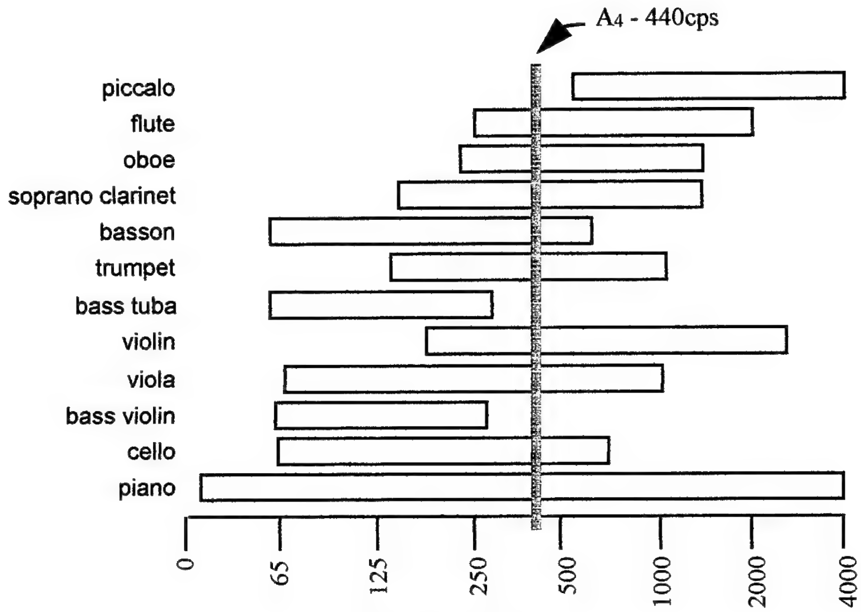
C_1	32	C_2	65	C_3	132	C_4	264	C_5	528	C_6	1056	C_7	2112
D_1	36	D_2	73	D_3	148	D_4	297	D_5	594	D_6	1188	D_7	2376
E_1	41	E_2	82	E_3	165	E_4	330	E_5	660	E_6	1320	E_7	2640
F_1	43	F_2	87	F_3	176	F_4	352	F_5	704	F_6	1408	F_7	2816
G_1	48	G_2	97	G_3	198	G_4	396	G_5	792	G_6	1584	G_7	3168
A_1	55	A_2	110	A_3	220	A_4	**440**	A_5	880	A_6	1760	A_7	3520
B_1	61	B_2	123	B_3	247	B_4	495	B_5	990	B_6	1980	B_7	3960

Sources: Data from Backus, John. *The Acoustical Foundations of Music.* New York: W. W. Norton & Company, 1977 and White, Harvey and Donald White. *Physics and Music - The Science of Musical Sound.* Philadelphia: Saunders College, 1980.
Notes: The decimal points have been dropped for readability. The outermost ranges of the scale (C_0-B_0 and C_8-B_8) are not shown because they contain values that are not obtainable by popular instruments. The letters are for the notes of the scale. The subscript number next to the notes designate the octave of the note.

Looking at how 440cps (A_4) places in the scale of notes (Table 2.2) we see that it represents the fourth octave and it falls right in the middle. From this example, I will assume that notes below the scale of A_4 are low notes and the notes above the scale of A_4 are high notes. The degree to which these notes are high or low depends on their distance from A_4.

Further examination of Table 2.2 also reveals that the frequencies of musical notes are not linear. That is, the spacing between the notes of each octave doubles as you travel up the scale. For example, the difference between A_3 and A_4 is 220cps while the distance between A_4 and A_5 is 440cps. Figure 2.2 gives a more accurate depiction of the frequency ranges of the selected instruments and how they fall in the musical scale. This view also makes it easier to see how A_4 relates to instruments ranges.

Figure 2.2 Adjusted Instrument Frequency Ranges

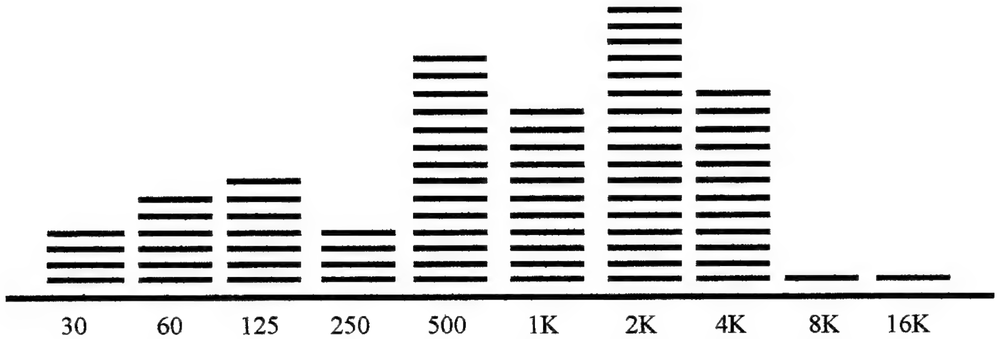


Cycles per Second

Sources: Data from Backus, John. *The Acoustical Foundations of Music.* New York: W. W. Norton & Company, 1977; White, Harvey and Donald White. *Physics and Music - The Science of Musical Sound.* Philadelphia: Saunders College, 1980; and Culver, Charles. *Musical Acoustics,* 4th ed. New York: McGraw Hill, 1956.

Viewing a spectrograph (stereo equalizer display) while listening to orchestral music strengthens my assumption. I played several pieces of music (primarily violin concertos) on my CD player and kept close tabs on what frequencies where peaking (Figure 2.3 is a close approximation of what the display looks like, the numbers along the bottom represent frequencies). When there were notes that I perceived as being predominately low, the bars to the left of 500 were the most active. Likewise, when I perceived notes to be high, the bars right of 500 were most active. Overall, the 500 bar was the most active.

Figure 2.3 Spectrograph



Closer examination of Figure 2.2 reveals that the frequency ranges of some instruments (piccolo, bass tuba, and bass violin) do not include A_4. Does this mean that those instruments can only be classified as high or low, depending on which side of A_4 they fall? When these instruments are heard from within an orchestra they do sound relatively high or low, but what about when the instrument is heard solo? A piccolo that played a scale from B5 (990cps) to E7 (2640cps) will surely give the impression of going from a low to a high note, but that entire range is high. Should the determination of high and low frequencies be made on the frequency range of music or the frequency range of the specific instrument? Unfortunately this topic is beyond the scope of this study and is reserved for further research.

Psychology of Color

My main interest in color lies in what emotions different colors portray. I hope to use color to play a large part in representing the emotive qualities of music. As with music, I am aware that color alone can not fully characterize emotion, but I believe it is a major piece of the puzzle.

As with music, color can also be broken down into basic properties. The three elements of color are as follows: hue (perceived color), brightness (dull to sharp and clear), and saturation (shallow to deep and strong) (Sharpe, 1974).

Colors have different meaning to many cultures. When I discuss a color having a certain emotion or feeling associated with it I am referring to American preferences. For a quick example, black is a color of mourning in our culture, but the opposite is true in some eastern cultures, where white is a color of mourning.

There have been a number of studies that have set out to investigate how people correlate emotions and colors. After examining the results of such studies and/or conducting their own research Birren (1961) and Sharpe (1974) came to the following general conclusions as noted in Table 2.3.

The results overlap in places and are not conclusive, but a general remark can be made of the data in whole. The warmer colors (red - yellow) are more energetic and happy, while the cooler colors (green purple) are more peaceful and calm.

Table 2.3 Color and Emotion Associations

Color	Birren	Sharpe
Red	Passionate, exciting, active	Excitement, stimulation, aggression
Orange	Jovial, lively, energetic, forceful	Excitement, stimulation, aggression
Yellow	Cheerful, inspiring, vital, celestial	Cheer, gaiety, fun,
Green	Quieting, refreshing, peaceful	Calm, security, peace
Blue	Subduing, melancholy, sober	Calm, security, peace
Purple	Dignified, pompous, mournful, mystic	Dignity, royalty, sadness
White	Pure, clean, frank, youthful	Purity, innocence, holiness
Black	Ominous, deadly, depressing	melancholy, sadness, depression

Sources: Data from Faber Birren. *Color Psychology and Color Therapy - A Factual Study of Color on Human Life.* New York: University Books, Inc., 1961.; Deborah Sharpe. *The Psychology of Color and Design.* Chicago: Nelson-Hall Company, 1974.

Deafness

The essence of this work is to provide an additional medium to which hearing impaired persons may achieve a fuller enjoyment from music. I do not know what it is like to be deaf or hearing impaired. The goal of my research in this area is gain some understanding of deaf perceptions.

Among the hearing impaired, there are relatively few with absolutely no sense of hearing; patterns of hearing loss can be very complex (Higgins, 1980). There is a vast range of hearing impairment. The difference lies in what frequency range they can

perceive. For example, the ear can perceive sounds between 20 and 20,000 cps, human speech is in the range of 250 to 4000 cps. Losing a relatively small portion of that range could render an individual incapable of hearing spoken words. My concern here is the perception of music. Obviously, musical instruments can traverse a larger frequency range than the human voice. Since there is no universal pattern of hearing loss I will not focus on any particular frequency range. Also, when I make or refer to statements about the capabilities of deaf people I am aware that these statements do not apply to all deaf people.

Because deaf people cannot hear music it does not mean that they cannot appreciate such musical concepts as harmony, dissonance, and variation (Padden and Humphries, 1988). There are three different types of music: ear music, eye music, and skin music (Zak, 1997). Through the eyes and skin, many of the properties of music can be learned and appreciated.

Eye Music

Eye music is observance of motion that mirrors properties of music. There is movement in everyday life that can be thought of as rhythmic, but a better example of eye music is poems expressed in sign language. The movement of the signs and the body language can communicate various musical properties. The following is a description by Padden and Humphries (1988) of a sign reading of a poem, "Windy, Bright Morning" written and performed by Clayton Valli (1985):

> The poem describes the edge of wakefulness and sleep and begins with a window and an external force:

Through the open window
with its shade swinging, sunshine, playful,
taps my sleepy eyes.

The hand, used to represent the shade, moves in a slightly irregular but not unpleasant rhythm.

Breezes dance in my room,
around my, not shy, but gentle,
letting me know that it's time
to get up! Slowly I wake,
my eyes stung by the sunlight
flashing past the swinging shade
that seems to know I'm deaf.

The presence of the light is unmistakable; the movement revolves around the center of the light

I stand up, tired, ignoring the light
chilled in the dancing air
that meets me by the window
I closely shut it. And with the shade still,
my room darkens.

The irregular movement abruptly ceases, and the room becomes silent. As Valli moves back to the familiar bed, movement is slow and comforting.

Happy
back under the covers,
I'm drowsy, purring, warm . . .

The audience, lulled by Valli's slow delivery, is unprepared for the next verse:

But, suddenly, how strange!
The shade flaps widely,
bright, dark, bright, dark, bright
Fierce wind flung open the window . . .
so bitter cold, so cold, the wind, the shade,
the storm!

The movement is wild and unpredictable. Valli as experiencer widens his eyes and moves his body with a sense of urgency.

Slowly I rise, and try to make them calm down.

As he moves toward the window, the window, formerly dissonant, changes again, beginning to come together in one organized and focused form:

The wind, the shade, dancing gracefully, happy.
One bright ray gently pulls me
to raise up the shade
like unwrapping a gift.
Warm sunlight tickles me,
morning breeze laughs with me . . .
Joyful, I welcome the day.
(Valli, 1985)

The feeling of dissonance, consonance, and tempo can easily be identified in this poem. The changes in energy are also representative of changes in moods. This is yet another example of how body movement can be described with musical terms which can lead to a musical description of emotions. This also supports the thought that such musical properties can be appreciated visually.

Skin Music

Skin music is feeling music via the vibrations through the air. Even people who are extremely deaf can still feel the vibrations of music through speakers (air) or the floor (Zak, 1997). This makes perfect sense because sound is nothing more than vibrations in the air. Depending on the pitch and volume those vibrations can be felt upon the skin, in other words, if it's loud enough and has enough bass.

Professor Daniel M. Berry of Technion University in Israel (Berry, 1997) told me that although he is nearly deaf, he hears rhythms very well, so well in fact that he is able to dance. He also enjoys rap music because of it's strong beat.

This is evidence that there is more than one way to appreciate the properties of music. The absence of hearing does not totally deprive the Deaf of an aural experience.

Previous Related Research

Color and Music Association

Synesthesia is a psychological phenomenon in which people have the simultaneous response in more than one sensory mode (Radocy and Boyle, 1979). Chromesthesia, a specific form of synesthesia, is a condition where audible sounds create, simultaneously, visual color as well and aural sensation (Cuteitta and Haggerty, 1987). Being able to associate color with music or any other audible sensations does not constitute chromesthesia since the connection to color comes after the sound.

Color Response to Music

In a study conducted by Karwoski and Odbert (1938), involving 148 college students, approximately 60 percent (87 students) had a color response to music. Of the 87 students, 65 percent experienced chromesthesia, 88 percent associated a color, and 51 percent felt a color response. They came to the conclusion that a majority of the population has some kind of association between color and music.

Karwoski and Odbert (1938) also noted the following findings: blue is associated with slow music, red is associated with fast music, light colors with high notes, dark colors with deep notes. Aside from red and blue there was no mention of the impact of other colors or if the test subjects came up with the same colors. Another interesting part of the study was that they found that the vertical dimension is related to pitch and that intensity may be denoted by depth.

Environment or Innate

The question to ask is whether color associations are innate or are acquired and learned from our individual environments. A study conducted by Cutietta and Haggerty (1987) sought to answer that question. They believed that there would be two possible conclusions. One, if music/color association is a product of environment then you would expect a strengthening of this association throughout the school years. Two, if music /color associations are due to early synesthesia then you would expect a constant response throughout the school years, perhaps getting weaker as one matures.

The study was conducted over three phases. The first phase involved subjects from elementary school, secondary school and college. Phase two involved subjects ages 3 to 11. Phase three involved subjects from college to senior citizens. All subjects listened to three different 30-second examples of taped music. The example were: (1) Gustav Holst's *Suite No. 1 in E♭,* third movement, "March," measures 1-36; (2) Modest Moussorgsky's *Pictures at an Exhibition,* fourth movement, "Bydlo," measures 1-20; and (3) George Frideric Handel's *Music for the Royal Fireworks,* "Bourrée," measures 11-26. Each musical piece was chosen because of its distinct and separate qualities. The "March" is majestic and vigorous, the "Bydlo" is plodding and laboring, and the "Bourrée" is lively (Cuteitta and Haggerty, 1987). From here forward any reference to the music examples will be the names in quotations.

Each subject listened to a music example and indicated which color they associated with the music. The subject were given a standard color wheel with the

following colors: orange, yellow, green, blue, purple, and red. The predominant color choices for each phase are listed in Table 2.4.

Table 2.4 Predominant Color Choice

	Phase 1 (Grades 1-college)	Phase 2 (Ages 3 - 11)	Phase 3 (college - 70s)
"March"	Red, all	Blue 3, 4, 9, 10 Purple 7 Red 5, 6, 8, 11 Orange 6 Yellow 8 Green 4	Red College -40s, 60s, 70s Yellow 50s
"Bydlo"	Blue, 1-6,8-college Purple, 7	Blue 9, 10, 11 Purple 3, 7 Red 5, 7, 8 Orange 6 Yellow 4, 7 Green (none)	Blue College, 20s, 50s, 70s Purple 30s, 40s, 60s
"Bourrée"	Yellow 1-2,4,6-college Orange, 3 and 5	Blue 5, 8 Purple 4 Red 3, 9 Orange 7 Yellow 6, 10, 11 Green 11	Yellow College - 40s, 60s, 70s Red 50s

Source: Data from Robert Cutietta and Kelly Haggerty. "A Comparative Study of Color Association with Music at Various Age Levels." *Journal of Research in Music Education*, 35, no. 2 (1987): 84-88.
Note: If an age indicator is listed twice that means there was a tie for that age group

There is consistency across age groups in phases one and three. The results for phase two appears to be random, but the colors selected in the other phases still have the highest concentrations for each musical example. No reasons were given for the scattered results in phase two.

Cuteitta and Haggerty (1987) discuss that the theory of chromesthesia can not be supported by phase one due to the inconsistencies with "Bydlo" and "Bourrée." Examining the differences in color selection of the two musical pieces one could argue that there are no inconsistencies worth mentioning. Recalling Table 2.3, one will notice

that the emotional responses to blue and purple are very similar, as well are the responses to orange and yellow.

The discussion that follows phase one mentions that music similar to the styles of "March" and "Bydlo" are commonly used in media that is targeted towards children, while Baroque style music like "Bourrée" is not. They say that this explains the inconsistencies in phase one. Rather, my speculation is that it explains the inconsistencies in phase two. Phase two looks like confusion. Children are bombarded with images and sound via today's media; I think this results in a brief bafflement over the formative years, which is sorted out as one matures.

In phase three, consistency is once again prevalent, with the same colors as phase one! The only major variations deal with individual in their 50s. Cuteitta and Haggerty (1987) speculate that it may be related to the mid-life "crisis" period of development.

After analyzing the data of this study, Cuteitta and Haggerty (1987) were faced with the following questions:

(1) If color/music associations are a conditioned response, why isn't there a gradual rise in consistency?

(2) If conditioning is from media, how does one explain the consistency of responses from older subjects who were not exposed to color media?

Researchers feel that the results from this and other studies points to a theory that color/music association is the result of some sort of sensory processing of music, and that this processing may be related to emotional responses (Cuteitta and Haggerty, 1987).

Manually Generated Visual Music

Typically, visual music involves a complex union of images and sound to create a experience that can be more expressive than either of the two mediums alone (Pocock-Williams, 1992). This visual music ranges from the depiction of a story to the abstract display of colors and images.

Even if the visuals do emphasize or complement the music, more than likely, they only deal with a subset of the music's properties. Keeping that in mind, I still find it useful to examine how different elements of music are dealt with in different applications.

Predetermined Animations

Even though the visual music is generated manually, computers can still be involved. Pocock-Williams (1992) used computers to generate the graphics for several pieces of music. The process she describes is as follow: (1) start with a pre-existing piece of music, (2) listen to music many times until she had a sense of the overall quality of matching images, (3) write a computer program to animate the work.

Below are descriptions of two pieces of music and her corresponding animations:

(1) Homage to Kandinsky: Improvisation (Williams, 1989). Wassily Kandinsky is an artist to whom Pocock-Williams credits her interest in visual music. The images for this piece were taken from one of Kandinsky's paintings: circles, rectangles, and triangles. The music begins subdued, the corresponding shapes are mostly gray in color, with the shapes emerging out of a black background. The second half of the music

becomes more dramatic. In response the shapes begin to pulsate. There is no mention as to whether the colors change with the mood of the music.

(2) Occam's Razor (Williams, 1989)**.** The music for this piece is described as tense, fast, and abstract. The predominant imagery consist of a series of parallel lines. The movement of the lines is at times erratic to give them a 'nervous' quality. The animation is laid over recorded live-action video (the contents of the video are not mentioned). Pocock-Williams describes the result as fast-paced and discordant with an unresolved ending. Again, there is no mention of a particular use of colors.

The above animations are interpretations of how music made the author feel about the music. Based on the descriptions, I don't believe that there was any attempt to use colors to symbolize the emotions portrayed by the music. Movement and shape were the major forms of representation. Movement was used to depict the tempo, while the shapes were what the author thought would best depict the music as a whole. There was no reference to the intensity of either musical piece.

Fantasia

Walt Disney's full-length movie, Fantasia, contains a series of classical music pieces that are accompanied by animation. The animations are interpretations of the music as seen by artist, not trained musicians. The narrator mentions that there are three types of music depicted in the movie: (1) music that tells a definite story; (2) music that does not tell a story, but does produce definite images; and (3) music that exist for its own sake. I believe the typing of music has a lot to do with the title given to the piece. The only music classified as 'music that exist for its own sake' was Toccata and Fugue in

D minor by Johann Sebastian Bach, its title is more a description of the music. Likewise, since the title is not explicit neither is the animation. The other animations in the movie were very explicit and didn't leave much to the imagination. For this reason I focused on Toccata and Fugue.

Before the animation begins, silhouetted images of the orchestra are displayed playing their parts. The background was lit by different colors: red, yellow, green, and blue. The majority of the time the color used seemed to be dependent on how much energy (volume or intensity) was coming from the focused instruments. For example, blue was used for the harps (passive), while red was used for the drums (powerful), green and yellow were used in the same manner, respectively. I did not notice a relationship between color and notes. At times when the energy of the music went from low to high the color shifted from blue to red.

When the animation began, the first thing I noticed was that some of the images were symbolic of the motions that a conductor or musician might make. For example, there were multiple bows at about 25 to 45 degree angles moving up and down to the music. The emphasis was no longer on the colors, but on having the abstract images represent parts of the music. Lines, circles and stars danced across the screen or moved across a imaginary terrain. Ascending, descending, and alternating notes were represented by the images doing the same with their movements, mapping the tempo at the same time.

The animations picked the most obvious elements of the music, melody and tempo, which gave the overall feel of the music. Watching the images without the music

did not produce the same effects. This is not surprising, since I believe the goal of the animation was to enhance, not represent, the music.

Automatically Generated Visual Music

From my research, I have found very few attempts to automatically generate visual music. When I did find them, the goal of the software was to accompany and enhance the aural experience of music with images and animation, not to provide an additional medium. Given the fact that the visuals are meant to heighten the experience, they only deal with a subset of the music's properties, most commonly pitch and duration. As with manually generated visual music, the work done in this area provides me with an excellent starting point and frame of reference.

Automatically Generated Animations

Pocock-Williams (1992) also did some work generating visual images from music automatically. She developed a 'visual' language consisting of basic shapes, colors, and linear movement. The computer controls time-sensitive operations such as scaling, translating, pulsating, and replicating. Attention is also paid to how objects enter, exit, and cross paths in the viewing area.

The software used in this project was SoundScape Pro MIDI Studio from Mimetics Corporation. SoundScape stored the input music-data as a MIDI file. The author wrote programs for extracting and analyzing data from the MIDI file, and creating the animation.

She used these four major steps for sound-to-music integration: (1) music input via SoundScape Pro MIDI Studio; (2) music analysis (3) decision making according to preset rules, and (4) animation generation.

Once the music is stored into the MIDI file the required data, pitch and duration, are extracted and stored into a text file which is then converted to integer format. The data is then read in at 10 second intervals for analysis. The program searches for four different patterns. If the pitches are all increasing, decreasing, alternating or flat they are replaced by UP, DOWN, ALT, and FLAT terminals, respectively.

Pocock-Williams (1992) provides the following example:

> Assuming the order of pitches from high to low is as follows:
>
> a b c d e f,
>
> a 10-sec phrase of notes that looks like
>
> a c a c c d f f d c a c a c c d f f d c a c a c c d f f d c
>
> would be replaced by a simplified pitch-time graph that looks like
>
> ALT UP DOWN ALT UP DOWN ALT UP DOWN

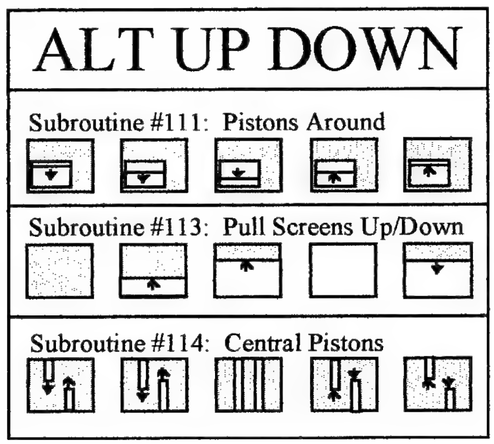
She further mentions that since ALT DOWN UP occurs three times it is a 'predominant pattern' and the whole thing will be reduced to one ALT DOWN UP.

It can be seen from this example that the relationship from music to animation will not be one-to-one. In the course of this ten second interval the music has phased through ALT DOWN UP three times, but whatever actions the animation will take on this occurrence will happen only once. This should give the general feel of the music, but I think it can be argued that something will be missing.

After each 10 second interval is analyzed the program selects, at random, one of at least five animation terminals that has been pre-classified as being a visual expression

of the selected music terminal. For the above example, the selected animation terminal would exhibit movement that corresponds to ALT UP DOWN. Figure 2.4 displays examples of three of the possible five animation terminals for ALT UP DOWN. Each animation sequence runs about 10 seconds. This process continues in 10 second intervals until the music is complete. No mention was made as to whether these animations perform their cycles once or many times in the 10 second interval.

Figure 2.4 Animation Terminals



Again, it is easy to see that while this may represent the overall feeling in music, it is quite possible to miss out on the many of the intricacies of the music. It is also worth repeating that this animation is not meant to stand alone, the music will be played simultaneously. It's main goal is to enhance the musical experience.

Screen Dance

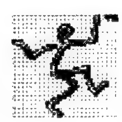
ScreenDance version. 1.0 J from Madeira Software, Inc. is a 32-bit CD player that comes with sound activated animations. Each animation displays real-time imagery in response to whatever music is in the computer's CD player.

ScreenDance accomplishes this by using Fast Fourier Transform (FFT) to analyze the audio signal coming from a CD player in to a tabulation of frequencies (pitches). From there it gives instructions to the selected animation. The exact process they used to go from frequencies to animation was not available.

The downloadable version of this software (http://www.madeira.com/dance.htm) contains the following animations: 3D spectrograph that plots the magnitude of the frequencies over time, lower notes on the left higher on the right; a stick figure dancer (see Figure 2.5); fractals, computer generated art that pulsates to the sound; kaleidoscopes that moves to the beat of the music; a pile of marbles; and actual soundwaves.

ScreenDance makes no explicit attempt to interpret the mood of the music. The animations are dictated by the rate of change in the tempo and pitch of the music.

Figure 2.5 ScreenDance Dancer



I spoke to Dave Young of Madeira Software, Inc, he said what they are trying to do with this software is to enable people to enjoy music to a fuller extent. Currently they are working on a native Windows 95/NT version of ScreenDance, with plans on releasing a ScreenDance SDK (software development kit) sometime in the near future, which will include all the libraries and interfaces you would need to create your own animations for the Windows version of ScreenDance. It will be designed in such a way to be relatively easy for 3rd parties to create new animation modules. New animation modules will be programmed in C/C++. The animation module will have has access to the raw digital

audio data, and can make use of included library functions for extracting frequency, intensity, and duration information.

CHAPTER 3

METHOD

The goal of the completed software is to capture the emotions/feelings of music and translate them to an animated display using color, shape, and motion.

Instrument

The instrument which I will focus will be the solo violin. Referring to Figure 2.1, one can see that the violin has no trouble reaching frequencies on either side of the standard A_4 (440cps). Given this fact, I will be able to use the predefined musical characteristics for producing various emotional expressions (Table 2.1)

The violin seems to be one of the more popular instruments. In most books that I've come across, which describe musical instruments, stringed instruments usually come first and violins are always the first in the string category. Culver (1956) notes that the violin is the basis of orchestral instrumentation and in the hands of a skilled musician, has an almost unlimited capability of conveying emotional concepts.

On a personal note, I am very partial to violin music. I find the violin able to portray a wide range of emotions.

Music

It was difficult to find a wide variety of violin solos on CD. There is a vast array of beautiful violin music available, but for the most part it is accompanied. Unfortunately, the violin solos that I have found seem to concentrate more on technique, which can make them somewhat difficult to enjoy.

My goal was to find two pieces of music, one that was primarily sad and another that was primarily happy. The two violin solos I selected are listed below:

24 Caprices for Solo Violin, Op. 1, no 4 in C Minor, composed by Nicolo Paganini, performed by Michael Rabin. This selection is primarily on the sad side, however the tempo increases after the first 60 seconds, therefore I only used the first minute. The melody is very disjunct and disturbed. I had to listen to it several times before I began to enjoy it.

Sonata no. 3 in C Major, Allegro Assai, composed by Johann Sebastian Bach, performed by Lara St. John. This selection is primarily on the happy side. I used the first 85 seconds of this piece. I enjoyed this selection the first time I heard it. Its melody is playful and cheerful.

I decided to add a third piece of music that does not fall into the violin solo category. The music I chose is the Theme From JAWS - composed by John Williams - performed by the Boston Pops Orchestra. This piece of music has a definite link to emotions for many people, whether they have seen this movie or not. Overall, I would classify this music is threatening, exciting and powerful. Since this is not a solo arrangement I didn't expect optimal results, but It did provide an interesting display. I

still collected valuable information from the reactions of those who watched the animation.

Music to Emotion to Animation

This process will consist of two major steps. First, the software needs to identify the emotion of the music. Secondly, the identified emotion must then be translated into color, shape, and texture. To identify emotion in music I used the data presented in Table 2.1 (Musical Characteristics for Producing Various Emotional Expressions) as a starting point. Likewise, I used the data in Table 2.3 (Color and Emotion Associations) as a starting point in representing the emotions visually.

Identifying Emotion in Music

Music can express a wide range of emotions, but I focused on those which I feel are core and easiest to identify. Bruner (1990) presented musical characteristics for six emotional expressions: serious, sad, serene, happy, exciting, and frightening. I focused on four of these: sad, serene, happy, and exciting. I feel that serious and frightening are both subsets of sad and serene, which is easy to see by comparing the attributes for all four (Table 2.1).

Bruner (1990) used six musical elements to describe the emotional expressions: mode, tempo, pitch, rhythm, harmony, and volume. Of these six, I only used three: pitch, volume, and tempo (duration). Taking a close look at Table 2.1 will reveal that of the different emotions listed, all have a different combinations of the three attributes that I chose. Harmony is not a factor since I'm concentrating on one instrument, in solo

performances. The rhythm of the music can be broken down into volume and duration. The mode of the music can be decomposed into frequency ranges.

The emotions I chose are on opposite ends of the spectrum; the sad side, which includes serene and the happy side, which includes exciting. I could have just chose happy and sad, but serene and exciting give me good reference points from which to expand. These two sides reflect different energy levels. Low energy emotional expressions like sad, serious, and serene are characterized by slower movements, which is depicted by slow tempo (long durations). Conversely, high energy emotional expressions, such as happy, angry, and joy are characterized by faster movements, which is portrayed by a faster tempo (short durations). So, what we have is a 'tempo divide', low energy emotions are portrayed by slower tempos and high energy emotions are portrayed by faster tempos.

As stated above, I used pitch, volume, and tempo to categorize emotional qualities in music. I took the descriptions of emotional expression for sad, serene, happy and exciting from Bruner (1990) and expanded from there. This provided me with four definitions from which to start, but left many other options unexplained. Given that pitch and volume can each be classified as (1) low, (2) medium, and (3) high and tempo as (1) slow and (2) fast. We are presented with 18 (3 x 3 x 2) possible combinations of the three attributes. Each side of the tempo divide includes nine combinations. Those nine combinations are broken down further on each side of the tempo divide.

Table 3.1 Emotional Expressions Related to Musical Elements for Violin

	Sad			Serene			Tempo Divide	Happy			Exciting		
	-	-	-	-	X	-		+	X	+	X	+	+
	X	-	-	X	X	-		+	-	+	X	-	+
	+	-	-	+	X	-		+	+	+	X	X	+
	Volume Divide			-	+	-		Pitch Divide			-	-	+
				X	+	-					-	X	+
				+	+	-					-	+	+
	Pitch	**Volume**	**Tempo**	**Pitch**	**Volume**	**Tempo**		**Pitch**	**Volume**	**Tempo**	**Pitch**	**Volume**	**Tempo**

Source: Data for top line of table extracted from Gordon Bruner, "Music, Mood, and Marketing." *Journal of Marketing* 54, no. 4 (1990): 100.
Note: Symbol meanings are as follows: **-** = slow, low, soft; **X** = medium; **+** = fast, high, loud. Actual meaning depends on which musical attribute symbol is attached. Expansion from the first line of the table are my own observations. The order of all combinations is pitch, volume, tempo.

Table 3.1 list all possible combinations of pitch, volume, and tempo*. As can be seen, a volume divide occurs on the sad side and a pitch divide occurs on the happy side. The expansion of the combinations beyond those given by Bruner(1990) are from my own observations and opinions. I spent many hours listening to various pieces of music to determine the combinations in Table 3.1.

On the sad side we have the nine PVTs partitioned into three categories based on volume. Looking at the three sad PVTs, the only difference between them is the pitch.

---

* PVT will be used for future reference to pitch, volume, and tempo, when mentioned together. A combination of three symbols -, x, or + may follow (e.g., PVT -x-) or stand alone denoting the value of each respective element. See the note following Table 3.1 for definitions of the symbols.

In violin music, I found that sad music can occur at all pitch levels, this emotion seems most dependent upon tempo and volume. The level of pitch can determine the intensity of the sadness. While listening to music, I found that the higher the pitch the more physically tense I became, I can actually feel my muscles tightening. The opposite would occur with lower pitches, it seemed easier to relax.

The three PVTs directly below serene are similar to sad except for volume. The differences among the three are only in pitch, which determines the level of sereness. The last three PVTs under serene are not explicitly emotional expressions of serene. They are combinations which are not necessarily sad or serene, but are on the same side of the tempo divide due to their slow tempo. The increased volume seems to cause an enlightenment of the emotion, possibly creating a bridge to emotions on the happy side. I do not personally know of any music that sustains high volumes at a slow tempo, instead music that fits this category may raise its volume temporarily for accent or impact.

On the happy side, pitch is the divider. I found that happy music can occur at different volumes. The lower volumes seems more playful and small. The louder music sounds more energetic and large. The same logic holds true for the first three combinations under exciting. The last three PVTs under exciting are similar to the last three under serene in that they are not necessarily happy or exciting, but they exist on the same side of the tempo divide due to their fast tempo. Unlike the sad side, it is a bit easier to see what emotions these PVTs may portray. In general, music with a fast tempo and low pitch can sound powerful.

So far, only two emotions have more or less precisely defined; happy and sad, and even they have three PVTs each. The emotions that the other PVTs portray will be defined automatically via the color and animation (shape, size, and texture). I believe that if the PVT is correctly classified, the visualization of the selected attributes will mirror the correct emotion. This will be explained in more detail later.

Portraying Emotion with Colors

After identifying the emotion of the music the next step is to use color to visually represent the emotion. Table 3.2 summarizes the conversion. The colors used are those of the standard color wheel and the color-emotion references are derived from Birren (1961) and Sharpe (1974) studies. Sad and happy have direct links to specific colors while serene and exciting point to two different colors.

Recalling Table 2.3, we see that blue and green share some emotion associations, but they do differ slightly. Green is quieting, refreshing and peaceful, while blue is subduing, melancholy, and sober. Blue seems to represent deeper emotions. For the musical element combinations in the serene category, those with lower pitches are related to blue, while the green is used for the higher pitches.

Orange and red are also similar, but different. Red is passionate, exciting, and active, while orange is jovial, lively, energetic, and forceful. Overall, red seems more serious, it is assigned those combinations under exciting that have a lower pitch. Since orange is more lively and closer to happy it is assigned those combinations under exciting that have a higher pitch.

Table 3.2 Emotion of Music to Color

Pitch	**Volume**	**Tempo**		**Emotion**		**Color**
-	-	-	→	Sad	→	Purple
-	x	-	→	Serene	→	Blue Green
+	x	+	→	Happy	→	Yellow
x	+	+	→	Exciting	→	Orange Red

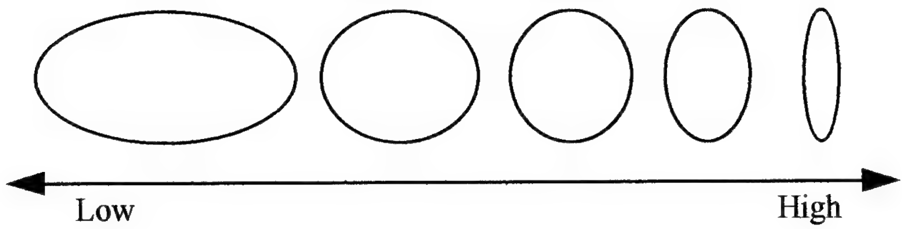
<u>Sources:</u> Data from Gordon Bruner, "Music, Mood, and Marketing." *Journal of Marketing* 54, no. 4 (1990): 100; Faber Birren. *Color Psychology and Color Therapy - A Factual Study of Color on Human Life.* New York: University Books, Inc., 1961.; Deborah Sharpe. *The Psychology of Color and Design.* Chicago: Nelson-Hall Company, 1974.

Object Shape and Movement

Since I will be focusing on solo violin there is a single object on the screen depicting the emotions it portrays. The shape of the object will depend on several factors involving the emotion, pitch, and volume.

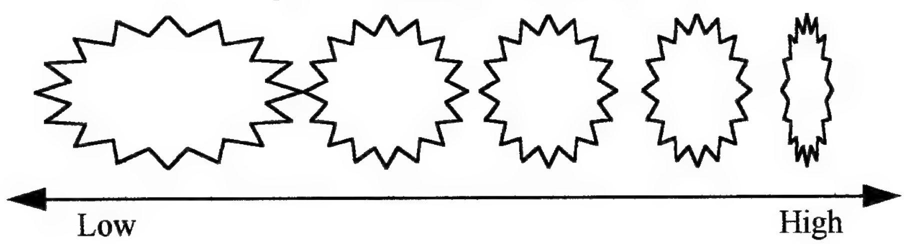
The default shape will be circular. Higher pitches will cause the shape to constrict on the horizontal plane, while low pitches will cause the shape to widen horizontally. As mention before, for me, higher pitches are more tense and compact than lower pitches. Also, the higher the frequency of a pitch the shorter its wavelength, conversely, lower frequencies have longer wavelengths. Constricting the shape horizontally for high frequencies is comparable to tensing, while widening horizontally is equivalent to a loosening of its containment. Figure 3.1 displays relative examples of a circular shape compared to the frequency of pitch.

Figure 3.1 Pitch Shapes



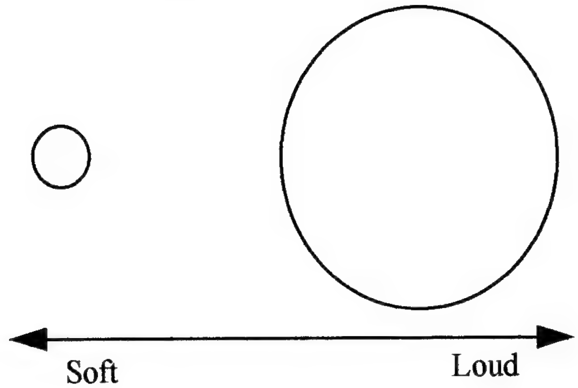
The object's outer texture is determined by comparing consecutive pitches. Conjunct pitches are considered sweet, happy, and lyrical while disjunct pitches are dramatic, energetic and agitated. Conjunct pitches will produce a smooth skin while disjunct pitches will produce a more jagged skin. Figure 3.2 shows the relative example of a disjunct texture. Figure 3.1 can also be considered an example of conjunct texture. The shapes will also mirror the level of the which the pitch is disjunct. A more disjunct pitch will produce a shape which is more jagged.

Figure 3.2 Disjunct Pitch Shapes



The objects size is determined by the current volume. Volume is related to energy level and depth. On a two dimensional plane the depth of an object may be represented by size. The closer the object is the larger it appears. Hence, the louder the music the larger the object.

Figure 3.3 Volume Size



Putting It Together

Each PVT is a sample of the music's attributes for a fraction of a second, a very small unit of the music as a whole. As each PVT is animated the emotion of the music will be revealed. Although, only two emotions are closely defined, a wide range of emotions can be identified and depicted using the above techniques for visual portrayal. For example, the feeling of surprise, while not specifically defined, can be portrayed easily.

In music, one way that a feeling of surprise can brought on is by a sudden change in volume level. Let's look at two consecutive PVTs, --+ and -++, which denote a drastic change in volume level and examine the corresponding animation. For PVT --+, the object would be wide, small and red. The transition to PVT -++, would call for the object to be wide, large, and red. The drastic change in PVTs would cause the object to explode from a small size to a large size in one frame of animation, therefore causing a surprise, something unexpected. The object in Figure 3.3 displays an extreme size difference that may be applied to this example.

Another example is the previously mentioned emotional expression of fright. I said that I considered fright a subset of the sad side. The characteristics of fright would give it the PVTs of ---, -x- and -+-, because of the varied volume. The PVTs would produce the following objects, respectively: wide, small, and purple; wide, medium size, and blue; wide, large, and green. The animation would show the object pulsing through the different colors and sizes. The texture of its skin would likely be ragged, since it's likely to be disjunct.

Other feelings of music like ascension (rise in pitch over time), crescendo (gradual increase in volume), and downward pull (decrease in pitch over time) to name a few will all be mirrored visually by the form the object assumes over time.

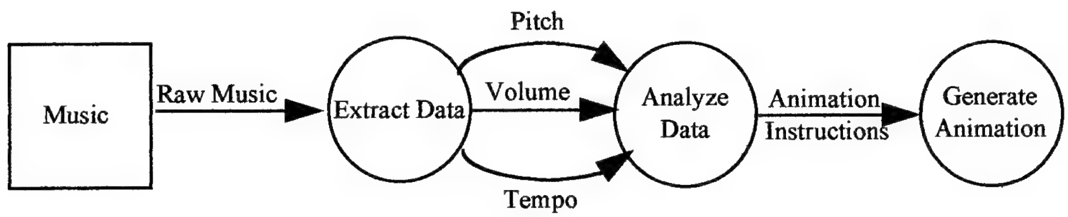
Software - See Symphony

The purpose of this software is to demonstrate my hypothesis that the emotions of music can be automatically identified and displayed visually. The software is named See Symphony, it's named for its ability to allow those to see what they cannot hear. The source code will not be listed for copyright reasons. The SDK provided by Madeira software is a Beta version, the release version is due out in early 1998.

Design

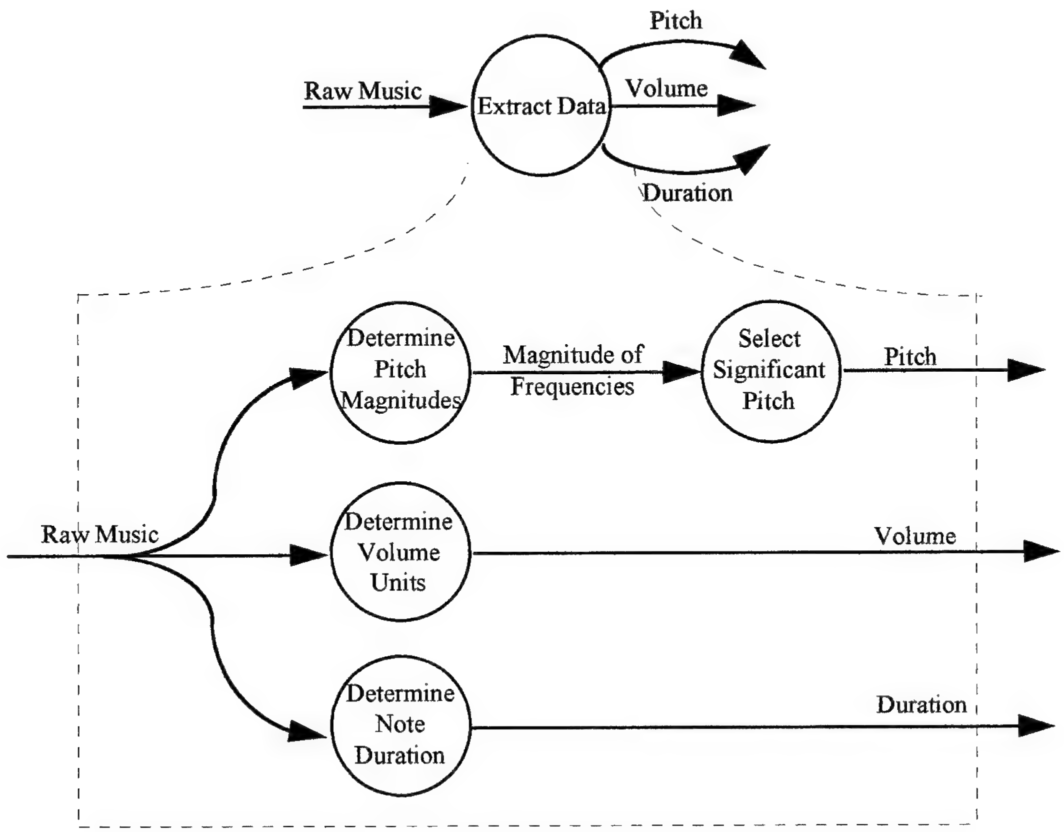
See Symphony accomplishes the following steps: (1) read in the music data, (2) extract PVT from music, (3) determine emotion of music, (4) generate and display frame of animation, and (5) repeat steps 1 though 4 until music is over. The following data flow diagram (Figure 3.4) depicts how the data will flow through the software.

Figure 3.4 See Symphony Data Flow - Level 1



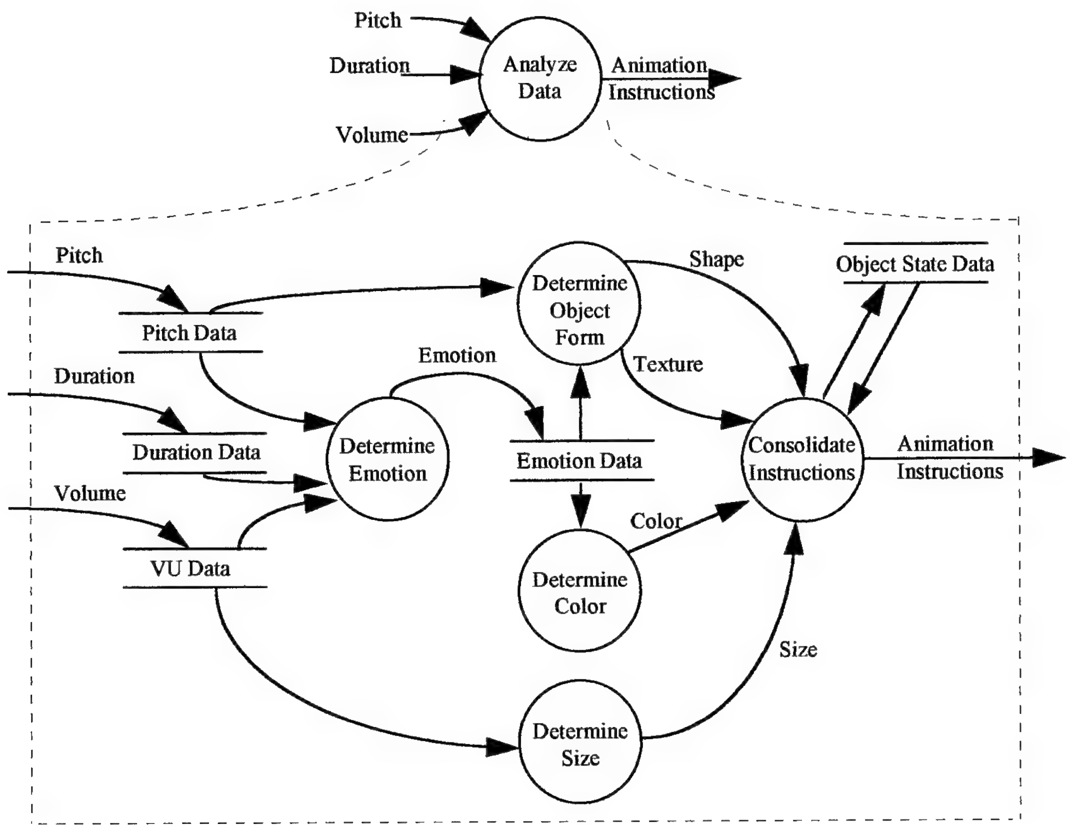
I used the ScreenDance SDK (Beta) developed by Madeira Software, Inc. as my platform. ScreenDance includes a musical CD interface and provides procedures (C/C++) for extracting data from raw music. The crux of my programming work consisted of writing procedures (C/C++) to analyze the data and generate the animation. Figure 3.5 displays a decomposition of the "Extract Data" bubble. All processes in Figure 3.5, except "Select Significant Pitch" and "Determine Note Duration" are provided by the ScreenDance SDK.

Figure 3.5 Decomposition of "Extract Data" Process - Level 2



Once the data is extracted it is analyzed for emotional properties, pitch, and volume. All of these factors are used to generate the animation instructions. The "Analyze Data" bubble is decomposed in Figure 3.6.

Figure 3.6 Decomposition of "Analyze Data" Process - Level 2



Challenges

There were two main problems that I had to address to make See Symphony mirror the music as closely as possible. First and foremost was the issue of frequencies. The function provided by Madeira Software Inc. that extracted the frequency information from the music stores the data in a linear form. As one can see from Table 2.2 (Frequencies of Notes) the frequencies in the musical scale are not linear. In order to properly classify the frequencies I created bins that represented each note on the scale. The frequency information from the frequency function was then sorted into the bins. From there I was able to more accurately determine which note was peaking at a given

moment. This also becomes important in determining whether a melody (consecutive frequencies) is conjunct or disjunct.

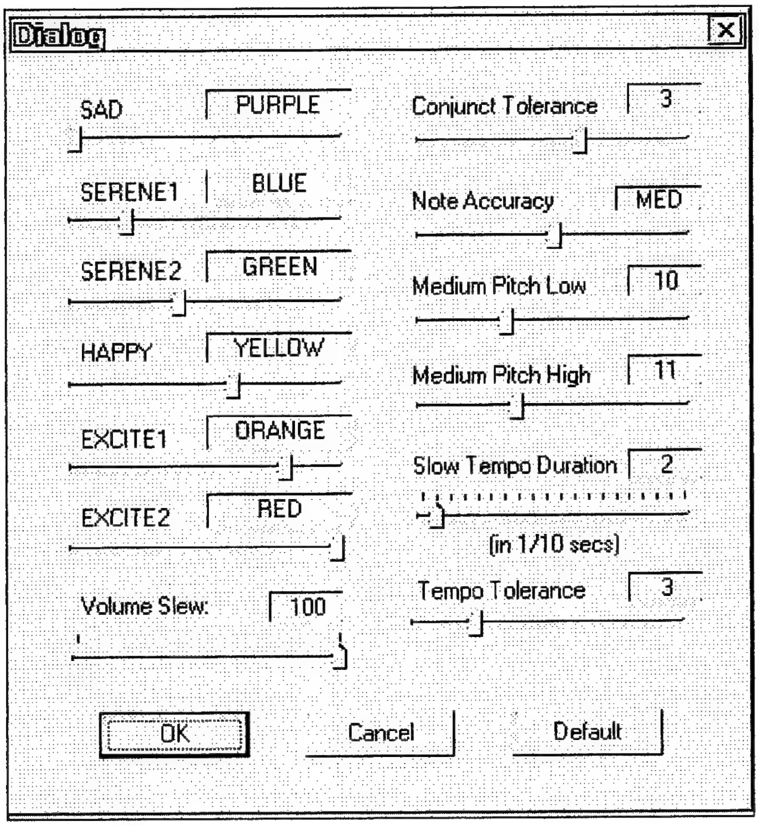
For See Symphony to decide whether consecutive frequencies were conjunct or disjunct it simply compares the bin numbers of the frequencies. If the bin numbers are more than a specified distance away from each other then they are labeled disjunct.

The second major issue was that of tempo. The function that Madeira Software Inc. would have provided looked at peaks in the volume to determine tempo. While this approach would work well for Pop music or any music with a drum beat or consistent accents I did not think that it work well with classical music. Instead I wrote a function that examines frequency duration as described in Chapter 2. The function measures the length of time that a note or silence is held and then makes a determination over time if the tempo is fast or slow.

Customizing

In order to make the animations work best for each individual I allowed for the customization of certain parameters, such as color and emotion associations. Other parameters are changeable, but these are mostly for experimentation to prevent the need to recompile for every adjustment. The control panel for the various changeable parameters is shown in Figure 3.7.

Figure 3.7 Customize Control Panel



According to the subject's preferences the colors for each emotion category could be changed to any one of the six of the standard color wheel (red, orange, yellow, green, blue, purple). The emotions associated with each category are listed in Table 3.3.

Table 3.3 Default Color to Emotion Association

Emotional Category	Default Color	Emotions/Feelings in Category
SAD	Purple	Sad, Mournful, Royal
SERENE 1	Blue	Subduing, Sober, Calm
SERENE 2	Green	Refreshing, Peaceful
HAPPY	Yellow	Happy, Cheerful, Fun
EXCITE 1	Orange	Lively, Energetic, Jovial
EXCITE 2	Red	Exciting, Passionate, Stimulating

The other options on the control panel in Figure 3.7 are for experimental and adjustment purposes, definitions for these parameters are listed in Table 3.4.

Table 3.4 Customization Parameters

Parameter	Function
Volume Slew	Sets the sensitivity to volume change. Ranges from 1 to 100. A higher number causes the software to be more sensitive to fluctuations in volume level. A low setting would require more of a change in the actual volume before the software senses a difference in volume level. Default is 100.
Conjunct Tolerance	Sets how many notes consecutive frequencies must be apart before a melody is considered disjunct. Ranges from 0 to 5. Default is 3.
Note Accuracy	Sets accuracy of frequency function. Setting are LOW, MED, or HIGH. A higher setting means more samples will be taken at each instance. More samples means higher accuracy, but it also requires more processor time. Default is MED.
Medium Pitch Low	Sets the lower boundary for medium pitch. The value is a bin number. Ranges from 1 to 29. Default is 8.
Medium Pitch High	Sets the upper boundary for medium pitch. The value is a bin number. Ranges from 1 to 29. Default is 15.
Slow Tempo Duration	Sets the time for a long duration in 1/10 seconds. Ranges from 1 to 10. Any duration greater than setting is considered long duration. Default is 2.
Tempo Tolerance	Sets the tolerance (out of 10) for long durations (slow tempo) Ranges from 1 to 10. If the specified number of long duration occurs out of 10 samples then the tempo is considered slow. Default is 2.

Running See Symphony

See Symphony works much better than expected. It is able to pick out very accurate information about the music at each instance. The one drawback is that it needs a relatively fast computer to work properly. The best output is achieved when the animation is between 20 to 30+ frames per second (fps). To achieve at least 20fps I used

a computer (notebook) with a 150MHz Pentium Processor with MMX technology. To achieve 30+fps I used a computer with a 166MHz Pentium Processor with MMX technology. The processor must do a large amount of computations many times a second. The result is a real-time visual, animated display of the music.

The majority of the test was accomplished with the 150MHz Pentium computer.

Testing

See Symphony was tested in two phases. The first phase involved 5 individuals, 3 of whom were deaf. Each individual watched the animations separately. Phase I was very structured and its purpose was to record individual reactions to music and animations to determine if See Symphony was capable of visually portraying the emotions of music. Phase II involved a group of 10 people, all hearing. The members of this group watched the animations at the same time. The purpose of this phase was simply to observe group reactions.

Phase I

The three deaf subjects and two hearing subjects watched/listened to the animations/music individually. I had hoped to have more hearing impaired participants, but two canceled due to illness.

The sample size for this phase is relatively small, but I don't believe the lack of many subjects is a crucial factor. If See Symphony works for a even one of the hearing impaired individual then I consider it a success.

Each person from this group filled out one of two questionnaires, depending on hearing ability. Samples of both questionnaires and cover sheets can be found in the appendix. The questionnaire is divided into three sections. Section I ask a few person questions. Section II asks the subject to match colors with emotional categories. The subjects were given samples of the six primary colors to aid in the color-emotion association. When the subjects completed Section II, I adjusted the color-emotion association parameters in the software (Figure 3.7) to match their selections prior to running the animation. Section III ask the subject to listen/watch three music example and record their reactions to the music and animations.

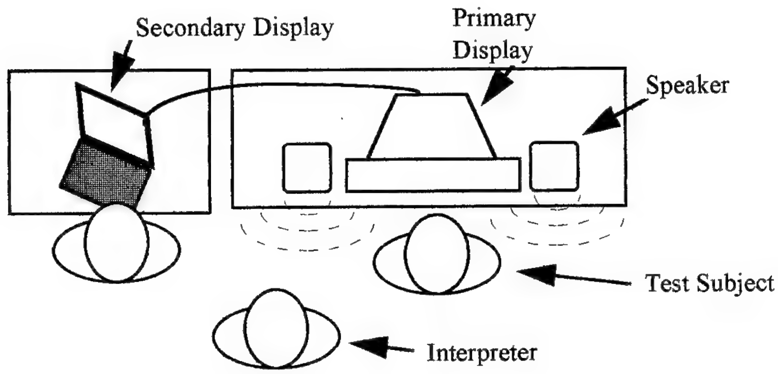
The main difference in the two questionnaires was how they record responses to the music and animation. The hearing impaired subjects were asked to describe the emotions or feelings that they thought the animation displayed. The hearing subjects were asked to describe the emotions or feelings that they thought the music portrayed. Subsequently, they were asked how well they thought the animation corresponded to the emotions and feelings of the music..

My reasoning for including the hearing subjects was to achieve a baseline for the emotions and feelings of the selected pieces, beside my own interpretations. It also was a way to find out if the animations corresponded well to the music for people with hearing. I felt if the animations corresponded well for the hearing subjects then I was on the right track.

I ran See Symphony from a notebook computer. The primary display was a 15 inch external monitor. The notebooks screen acted as the secondary display. All

subjects could only see the primary display. Figure 3.8 shows the relative positioning of myself and the test subjects. An interpreter was present during the sessions with the deaf subjects.

Figure 3.8 Individual Presentation Layout



There were speakers on either side of the monitor, each of these was set at high volume. The deaf subjects were encourage to make contact with the desk or speakers to pick up any vibrations that would emanate from the speakers. All three hearing impaired subjects did so during the course of the testing.

During the course of the test I did not look at any of the music/animation responses nor did I influence the subjects in any way.

Phase II

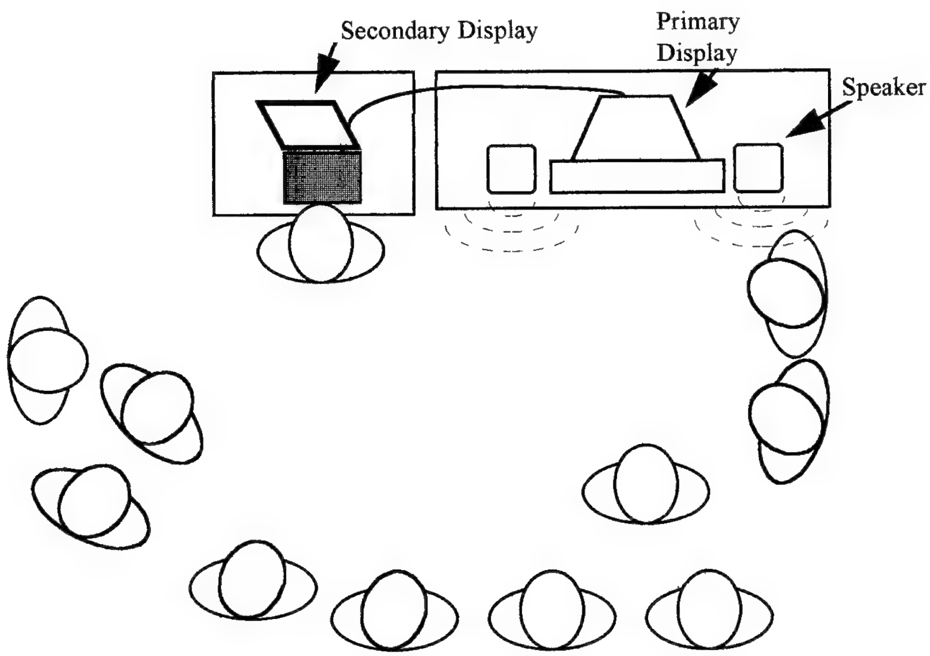
The ten participants in this phase were all hearing. All ten are either employed or associated with a business called Meeting the Challenge, Inc., located in Colorado Springs, Colorado. Meeting the Challenge produces software and hardware products to aid in and improve the lives of those with disabilities. Given the nature of their business,

I felt that these individuals were well suited to share their thoughts and ideas on See Symphony. More information about this business is available on the Internet at http://www.mtc-inc.com.

The individuals in this group did not fill out questionnaires, but some did document their reactions. These reactions can be found in the Appendix D.

Figure 3.9 represents the general position the two displays and the participants in the room during the group presentation.

Figure 3.9 Group Presentation Layout



All in the room had a good view of the monitor, also some could see the smaller secondary display on the notebook computer. Due to the orientation of the display, size of the room, and the number of people, some had a better view than others.

CHAPTER 4

RESULTS

Questionnaire Results

The results of the questionnaires are divided into two categories: hearing impaired and hearing. Each subject read cover letters which gave a description of the project and instructions regarding the music animation. These cover sheets can be found in the appendix along with the questionnaires.

Hearing Impaired Results

The following tables list the questionnaire responses for the hearing impaired subjects. Table 4.1 corresponds to the first section of the questionnaire which gathers some personal data. Table 4.2 covers Section II, which ask the subjects to match colors with emotional categories. Table 4.3 is the subjects' response to the each of the three animations described in Section III.

Table 4.1 Responses to Questionnaire (Hearing Impaired)

Questionnaire Questions	Subject 1	Subject 2	Subject 3
Age?	62	15	15
Level of Hearing Impairment?	Full	Partial. Can hear close noises in right ear and far noises in left ear	Partial. Can hear loud noises.
Hearing Impaired from birth?	No. Lost hearing at age 13.	No. Lost hearing at age 6.	No. Lost hearing at 18 months
Use any devices to aid hearing?	No.	Yes. Colloquial implant	No.
Any Experience with music?	Yes. Listening and singing as a child. No preferences	Yes. Listening. No preferences	No.
Ever been involved in other studies involving music and hearing impairment?	No.	No.	No.

Table 4.2 Color Selection (Hearing Impaired)

Emotion Category	Default	Subject 1	Subject 2	Subject 3
SAD	Purple	Purple	Orange	Red
SERENE 1	Blue	Blue	Red	Yellow
SERENE 2	Green	Green	Yellow	Purple
HAPPY	Yellow	Red	Blue	Green
EXCITE 1	Orange	Orange	Green	Blue
EXCITE 2	Red	Yellow	Purple	Orange

Note: The subjects were asked to select a color that they felt most closely portrays the emotions/feelings in each given category. They drew lines from each color to an emotional category. A swatch of each color was provided to aid in the visualization process.

Table 4.3 Responses to Music/Animation (Hearing Impaired)

Music	Subject 1	Subject 2	Subject 3
24 Caprices for Solo Violin, Op 1, No 4 in C Minor - Paganini	Feels subdued, calming and feels good	Good	Felt a little bit like loud (1 time)
Sonata No. 3 in C Major, Allegro Assai - Bach	Emotional, want to get up and dance. Great!	Exciting	Could hear (loud parts), loud and exciting
Theme from JAWS - John Williams	Feels great - wild!! Fast dancing music which makes you want to let go and dance wildly!	Exciting	Preferred lower volume shapes. Fun, preferred this one

Notes: The subjects were asked to describe the emotions or feeling the animation displayed.

Hearing Results

The following tables list the questionnaire responses of the hearing subjects. Table 4.4 corresponds to the first section of the questionnaire which gathers some personal data. Table 4.5 covers Section II, which ask the subjects to match colors with emotional categories. Table 4.6 is the subjects' response to the each of the three animations described in Section III.

Table 4.4 Responses to Questionnaire (Hearing)

Questionnaire Questions	Subject 4	Subject 5
Age?	48	37
Any Experience with music?	Yes. I listen to radio music at work and CD's at home on stereo and computer. I am a mood listener: hard busy day = loud, hard rock or metal; easy day = soft rock or easy listening. Periodically listen to Bach, Wagner, or Tchaikovsky	Yes. Flute player since grade 4, participated in marching band and orchestra through grade 12. Like a wide variety of music: blues, alternative, "oldies", bluegrass, and some classical
Ever been involved in other studies involving music and hearing impairment?	No.	No.

Table 4.5 Color Selection (Hearing)

Emotion Category	Default	Subject 4	Subject 5
SAD	Purple	Purple	Purple
SERENE 1	Blue	Blue	Blue
SERENE 2	Green	Green	Green
HAPPY	Yellow	Orange	Yellow
EXCITE 1	Orange	Yellow	Orange
EXCITE 2	Red	Red	Red

Note: The subjects were asked to select a color that they felt most closely portrays the emotions/feelings in each given category. They drew lines from each color to an emotional category. A swatch of each color was provided to aid in the visualization process.

Table 4.6 Responses to Music/Animation (Hearing)

Music	Subject 4	Subject 5
24 Caprices for Solo Violin, Op 1, No 4 in C Minor - Paganini	(Music) Piece seemed powerful and yet soothing with some struggle (Animation) The themes were there, but were somewhat confusing, didn't flow.	(Music) Soft, subtle feelings, some sad, but immediately relieved - not too serious (Animation) Great, liked the size changes - large to small - really expressed the music. Color changes were a little confusing until I relaxed and just listened.
Sonata No. 3 in C Major, Allegro Assai - Bach	(Music) Piece seemed light more active and felt friendlier and happy (Animation) Corresponded well and seemed closer to the theme, more understandable.	(Music) Perky, playfulness, almost like a child wanting to go play, tugging at mother's hand, who holds him back with a little restraint (Animation) Good, The spikes showed the staccato of the music, with vibrant colors emphasizing the happy feelings.
Theme from JAWS - John Williams	(Music) Experienced a building of emotion that began little and went to powerful, fear, and anxiety. (Animation) Corresponded well, wasn't confusing because the progression was evident	(Music) Deep, dark, and growing at the beginning, a little ominous, but then changing to something very expressive, a little lighter. (Animation) Very well - small and dark, but growing, changing color and sharpness towards the end.

Note: The subjects were asked to describe the emotion or feelings that they thought they music portrayed. Then they were asked how they thought the animation corresponded to the emotions and feelings of the music

Discussion

This discussion covers data from the questionnaires of both the deaf and hearing subjects. Topics discussed are the color-emotion associations, responses to the animations, and general observations.

Color-Emotion Association

The color-emotion association for most subjects was very close to the default colors. However, the color-emotion association of the two teenage (15 year-old) subjects, Subjects 2 and 3, was dramatically different. This difference is very interesting especially in this age group. The results are very similar to Phase 2 of the study conducted by Cuteitta and Haggerty (1987) discussed in Chapter 2 of this thesis. One logical explanation for this difference is that these two subjects are in the middle of their pubescent years and are probably just beginning to get a foothold on their emotions.

While their color choices are not identical to each other they are similar, especially in the grouping of colors. In general they selected the warmer colors to represent the peaceful and calmer emotions and selected the cooler colors to represent the energetic and happy emotions. Even though there were differences in the other subject's selection, they kept the warm colors with the happy and energetic emotions and the cooler colors with the peaceful and calmer emotions.

This shows that, for a large audience of different age groups, a default color selection may not provide everyone with a similar experience.

For this work, the difference in color selection is interesting, but not a huge factor. The color-emotion association within See Symphony was customized for each subject based on their selections.

I would have been interested in some younger subjects, but it may have been difficult to explain some of the emotional categories accurately, as well as getting accurate color associations.

Responses to Animation

The responses to each piece of music will be discussed individually. Overall the subjects followed the instructions well. Subjects 2 and 3 did tend to get distracted at times, but they were still able to provide worthwhile feedback.

24 Caprices for Solo Violin, Op. 1, no. 4 in C Minor by Paganini. This piece of music was selected for the sad and serene qualities of its first minute. When the animation runs it primarily uses the colors of the sad, calm, and peaceful emotional categories. Other colors did show, but their appearance was appropriate. For example, when the tempo would increase for an instance the color would change to a 'happier' color.

The hearing subjects agreed that the piece was subtle and soothing. It was also noted that there seemed to be some struggle with in the piece. This probably due to the highly disjunct melody.

The hearing subjects also agreed that the animation corresponded to the animation, but they differed on how well. Subject 4 noted that theme were there, but they did not flow very well and were confusing. This subject said that he did not care for the music. This and the fact that the music is highly disjunct could be cause for his interpretation. On the other hand Subject 5 felt that the animation corresponded well to the music. Subject 5 also pointed out something very important. She said the color changes were confusing until she relaxed and just listened. I believe for the animations to work well you must watch them the way you listen to music. That is, pay close

attention, but don't try to analyze and dissect every instance. Most important of all, relax.

The responses from the deaf subjects were also interesting. Tables 4.3 and 4.6 reveal that Subject 1's response closely matched that of the hearing subjects. Subject 2 and 3 were less revealing, but informative nonetheless. Subject 2 said the animation portrayed a good feeling, which is close to subdued and calm. Subject 3 can only hear loud noises, he reacted to some of he sounds that he could hear. As mentioned before, the speakers were turned up to a high volume. At some of the peaks (volume) in the music Subject 3 was visibly annoyed. Although those were the only sounds he could hear he seemed very sensitive to them. I believe it is comparable to sitting in a dark room and turning on a bright light.

Sonata no. 3 in C Major, Allegro Assai by Bach. This piece was chosen for its playful and cheerful melody. The animation primarily used colors of the exciting, happy, and lively colors. As with the first animation, other colors did show, but they appropriately followed the mood of the music.

Table 4.6 reveals that subjects 4 and 5 agreed with this assessment of the music. Subject 5 gave a particularly in depth and interesting description. Subject 5 also mentioned that the colors emphasized the happy feelings of the music. Subject 4 stated that this animation corresponded to the music much better than the first animation. The fact that the music was more pleasant could have affected his decision.

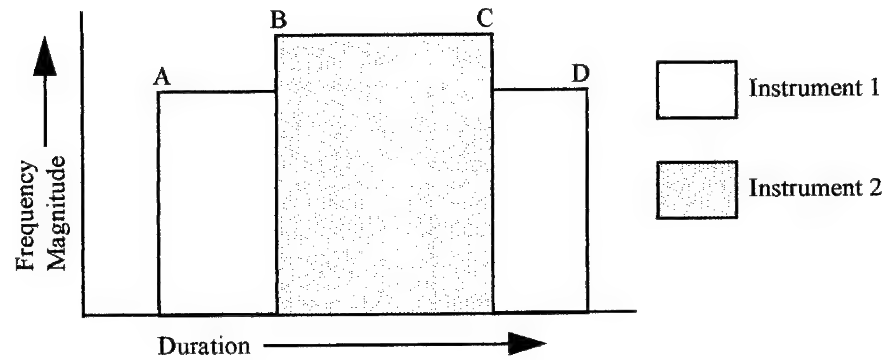
Subject 1 expressed that it made her want to get up and dance. Subjects 2 and 3 both found the animation for this music exciting. If you compare the reactions of Subject

2 to the works by Paganini and Bach, you can see that the animations are presenting the correct emotions for the music. There is an elevation of emotion between the two pieces and there is also a corresponding elevation in his responses.

Theme from JAWS by John Williams. The software is made to handle solo instruments, specifically the violin, but I thought it would be interesting to see how it worked with a full orchestra. One problem that was very apparent was that the software has a difficult time identifying the tempo properly when there are multiple instruments playing. It has the most problem with identifying slow tempos. The software examines the duration of the most significant frequency to determine the tempo. If two or more instruments are playing it's unlikely that are playing the same frequencies at the same moment at the same magnitude.

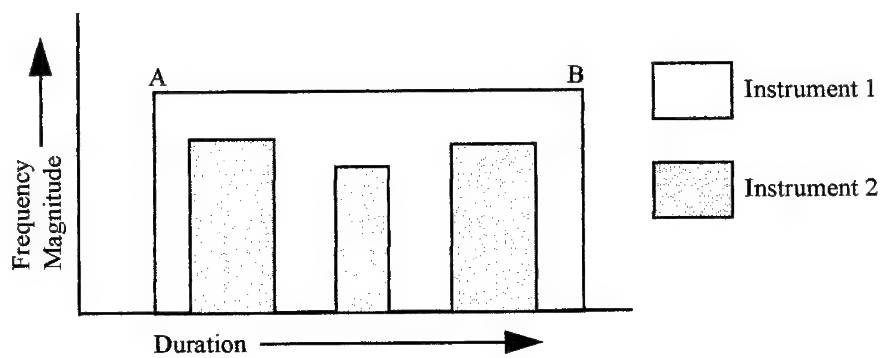
With one instrument See Symphony measures the time from the beginning of one frequency to the end of that frequency. In Figure 4.1 two instruments are playing separate notes of different duration and magnitude. Instead of measuring the time from point A to D for a solo instrument See Symphony now measures from A to B, from B to C, and C to D. See Symphony sees it as one instrument changing notes three times instead of two instruments playing one note. When the tempo is analyzed See Symphony will determine a faster tempo than it should.

Figure 4.1 False Fast Tempo Identification



The same thing can happen in reverse. A high magnitude, long duration frequency can mask the notes of another instrument playing at a lesser magnitude.

Figure 4.2 False Slow Tempo Identification



In Figure 4.2, again there are two instruments playing separate notes of different duration and magnitude. This time See Symphony will measure the duration from A to B and miss all of the durations of instrument 2. This will falsely identify the tempo as being slow when it is actually fast.

If the tempo is identified incorrectly then the emotion will be displayed improperly. Recall from Table 3.1 Emotional Expressions Related to Musical Elements for Violin, that the tempo plays a major role in identifying the emotion of the music.

With all this in mind I did not expect the theme from Jaws to be very accurate in determining the slow tempos when multiple instruments were playing.

Even with these known limitations the animation did very well and the responses reflected such. Subjects 4 and 5 both noted a building of emotions from the music: fear, anxiety, and anticipation. They both agreed that the animation corresponded to the music well. Both commented that the same building of emotion was evident in the animation.

All hearing impaired subjects enjoyed this animation the most. Subject 2 thought it was exciting. Subject 3 only noted that he preferred the lower volume shapes. At lower volumes the shapes are smaller, when the volume builds the shape gets larger. Subject 3 could see when an unpleasant sound was coming.

Subject 1 said that the animation made her feel like dancing wildly. That feeling is very apparent towards the end of the piece when the music becomes chaotic.

General Observations

While each of the deaf subjects was watching the animations I was watching them for physical reactions. The most obvious reaction was to volume. A sudden increase in the volume causes the image on the screen to grow rapidly. When an increase in volume occurred the subjects would move their heads back slightly just as a hearing person would if confronted with a sudden load noise. Subject 2 and 3 could hear loud noises, but Subject 3 was completely deaf, so I could be sure that her reaction was from the animation.

The deaf subjects also smiled often during the animation. I assumed that they were enjoying the animations. They all confirmed this suspicion at the end of each session by telling me that they enjoyed it and would like to see more.

I found this test to be very successful. It proves my hypothesis that the emotions of music can be automatically identified an displayed visually. Although, See Symphony is not perfect, it goes a long way to proving what can be done.

Group Reactions

As mentioned before, the group observation was less structured and less controlled than the sessions in Phase I. I simply observed and gathered data during and after the presentation.

Everyone enjoyed the display, but what was the most interesting was that the individuals who had the best reaction to the animation were closer to the display. Most agreed that animation corresponded to the music, but those who were farther away were not satisfied with changing of the colors on the monitor. They mentioned that the color change was too rapid or did not hold long enough, or was too erratic to portray an emotion. Also, some individuals farther away from the primary display preferred the animation on the secondary display. The secondary display had a slow refresh rate which caused it to leave a shadow of the previous images on the screen for a few milliseconds.

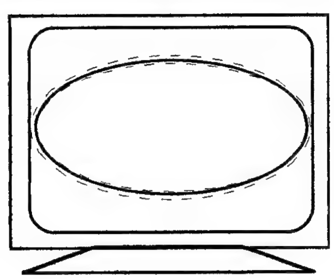
Discussion

The fact that those individuals closest to the display had the most positive reactions and a more complete experience supports the fact the animation is similar to

music. As mentioned in Chapter 2, in order to fully appreciate music you must actively listen to it. The degree to which music affects us depends a great deal on how we perceive it. There is a distinction between hearing and listening to music. Likewise, with the animations it is necessary to give it your full attention. For the animations to be more effective one must watch and absorb the animation, not just simply look.

Another reason that those closer to the display had a more positive experience could also be due to the fact that they were in a direct line of the soundswaves from the speakers. As with Phase I, the volume was set rather loud. The individual closest to the monitor would have been able to feel the music through the sound waves. The vibrations of the music emphasizes the shapes used in the animations. For example, a loud, rumbling low pitch, would produce a large, wide, vibrating shape as seen in Figure 4.3. The ability to experience both the vibrations and the animation would only enhance the experience.

Figure 4.3 Display Simulation



Another point must be made regarding the changing of the colors. If you focus on the rate of which colors change then you are trying to force an interpretation of the emotions that are being displayed. Rather, you should just absorb what is happening and

emotions will become evident. Subject 5 in Phase I noted that she felt the color changes were a little confusing until she relaxed and just listened.

I received e-mailed responses from five members of the Phase II group regarding See Symphony. Their complete messages can be found in Appendix D. I inserted a note at the top of each letter stating the individuals relative position to the primary display, if known.

CHAPTER 5

CONCLUSIONS AND FURTHER RESEARCH

Conclusions

Music is capable of representing a wide range of feelings and emotions. The emotions and feeling are complex in their form and they develop over time, but they are comprised of basic elements: pitch, volume, and tempo. These three properties have allowed me to identify the emotions that are portrayed by music.

Color can have a deep effect on our moods. Colors are consistently associated with emotions and feelings. Color is a natural visual means of expressing emotion. I have used color to represent the emotions and feeling of music.

Pitch, volume, and tempo also correlate to physical shapes and movement. I have incorporated these elements into the animations.

The subset of our population who are not able to enjoy music as it was meant to be enjoyed will now be able to see what was not fully available to them. Music is too beautiful to limit its audience. See Symphony translates music into a visual form allowing the emotions of music to be portray visually. Music can be enjoyed and appreciated via other senses besides hearing.

I set out to show that it is possible to automatically identify the emotions portrayed by music and display those same emotions visually. I have accomplished this goal.

Further Research

The first thing that needs to be accomplished is to use a larger sample size of deaf subjects. See Symphony seemed to be heading in the right direction with the limited number of subjects used in this study, but a more statistically significant sample size must be used to positively confirm the results.

Solo violin was used because of its obvious ability to portray emotions, its popularity, and it wide frequency range. The next step is to incorporate other instruments. The primary area of inspection when dealing with other instruments must be their frequency range. I based the middle of the violin's range on A_4. As noted in Chapter 2, not all instrument include A_4 in their frequency range. Should the frequency of a given note be considered in absolute or relative terms. In other words, should a note be determined high, medium, or low based on where it falls among the frequencies achievable by all instruments or should it be measured based on the frequency range of the instrument playing the note?

The timbre of an instrument becomes an important factor, especially when that instrument is compared to others. Timbre was briefly mentioned in this study, but not dealt with since I was only concerned with the violin. Do some instruments typically sound happier than others? Will different combinations of instruments change the perceived timbre of another?

Several people who viewed See Symphony mentioned that they preferred the display on the notebook computer. The notebook's display has a visual memory due to its relatively slow refresh rate. When an image is displayed, the previous image is still visible for a few milliseconds. This gives the previous images the illusion of fading away instead of a crisp transition as it would be on a standard computer monitor. Would a smoother transition further enhance the portrayal of emotions in the animation? If all the animations used a fading transition would it smooth out sharp music? It would probably enhance the experience in some cases, but not properly represent the music in others. There would need to be a way to determine the type of transition to use in a given situation.

What I've accomplished is to allow hearing impaired individuals to see a solo. When the same work is done for all orchestral instruments, then the Deaf will truly be able to see a symphony.

REFERENCES

Bach, Johann Sebastian. *Works for Violin Solo, Partita no. 2 in D Minor, Sonata no. 3 in C Major*, Lara St. John. Well Tempered Productions compact disk WTP 5180.

Backus, John. *The Acoustical Foundations of Music.* New York: W. W. Norton & Company, 1977.

Berry, Daniel, Computer Science Department Technion ISRAEL. Electronic mail conversation. 19 August 1997.

Birren, Faber. *Color Psychology and Color Therapy - A Factual Study of Color on Human Life.* New York: University Books, Inc., 1961.

Bruner, Gordon. "Music, Mood, and Marketing." *Journal of Marketing* 54, no. 4 (1990): 94-102.

Brusatin, Manlio. *The History of Colors*, trans. Robert Hopcke and Paul Schwartz. Boston: Shambhala, 1991.

Christ, William et al. *Materials and Structure of Music*, 3d ed. New Jersey: Prentice-Hall, Inc., 1980.

Cook, Nicholas. *Music, Imagination, and Culture.* Oxford: Clarendon Press, 1990.

Culver, Charles. *Musical Acoustics,* 4th ed. New York: McGraw Hill, 1956.

Cutietta, Robert and Kelly Haggerty. "A Comparative Study of Color Association with Music at Various Age Levels." *Journal of Research in Music Education*, 35, no. 2 (1987): 78-90.

Eargle, John. *Music, Sound, and Technology,* 2d ed. New York: Van Nostrand Reinhold, 1995.

Fantasia, prod. Walt Disney, 119 min., Walt Disney Company, 1940, videocassette.

Fay, Todor. "Writing a SoundScape Module in C." Amazing Computing, 2, no. 5 (1987): 27-39. Quoted in Lynn Pocock-Williams. "Towards the Automatic Generation of Visual Music." *Leonardo*, 25, no. 1 (1992): 32.

Goldman, Alan. "Emotions in Music (A Postscript)." *Journal of Aesthetics and Art Criticism* 53, no. 1 (winter 1995): 59-68.

Higgins, Paul. *Outsiders in a Hearing World - A Sociology of Deafness.* Beverly Hills: Sage Publications, 1980.

Karwoski, Theodore and Henry Odbert. *Color Music, Psychological Monographs*, 50, no. 2. Ohio State University, Columbus, 1938. Quoted in Faber Birren. *Color Psychology and Color Therapy - A Factual Study of Color on Human Life.* New York: University Books, Inc., 1961.

Padden, Carol and Tom Humphries. *Deaf in America - Voices from a Culture.* Cambridge: Harvard University Press, 1988.

Paganini, Nicolo. *24 Caprices for Violin Solo, Op. 1.* Michael Rabin. EMI Records LTD compact disk CDM 0777 7 64560 2 7.

Pocock-Williams, Lynn. "Towards the Automatic Generation of Visual Music." *Leonardo*, 25, no. 1 (1992): 29-36.

Politoske, D. *Music.* 2d ed. New Jersey: Prentice-Hall, Inc., 1979.

Radford, Colin. "Emotions and Music: A Reply to the Cognitivist." *Journal of Aesthetics and Art Criticism* 47, no. 1 (winter 1989): 69-76.

Radocy, R and J. Boyle. Psychological Foundations of Musical Behavior, Springfield: Charles C. Thomas, 1979. Quoted in Robert Cutietta and Kelly Haggerty. "A Comparative Study of Color Association with Music at Various Age Levels." *Journal of Research in Music Education*, 35, no. 2 (1987): 78-90.

Screen Dance Version 1.0 J. Madeira Software, Inc. 1996.

Sharpe, Deborah. *The Psychology of Color and Design.* Chicago: Nelson-Hall Company, 1974

SoundScape Pro MIDI Studio. Mimetics Corporation. 1987. Quoted in Lynn Pocock-Williams. "Towards the Automatic Generation of Visual Music." *Leonardo*, 25, no. 1 (1992): 32.

Storr, Anthony. *Music and the Mind.* New York: The Free Press, 1992.

Valli, Clayton. *Windy, Bright Morning.* Washington D.C.:Gallaudet College. 1985. Video. Quoted in Carol Padden and Tom Humphries. *Deaf in America - Voices from a Culture.* Cambridge: Harvard University Press, 1988.

Wells, Alan. "Music and Visual Color: A Proposed Correlation." *Leonardo*, 13, no. 2 (1980): 101-107.

White, Harvey and Donald White. *Physics and Music - The Science of Musical Sound.* Philadelphia: Saunders College, 1980.

Williams, John. *By Request...The Best of John Williams*. Boston Pops Orchestra. Philips compact disk 420 178-2.

Williams, R. Stuart. "Homage to Kandinsky" and "Occam's Razor." Score. 1989. Quoted in Lynn Pocock-Williams. "Towards the Automatic Generation of Visual Music." *Leonardo*, 25, no. 1 (1992): 31.

Young, David. Madeira Software, Inc. Telephone conversation. 19 August 1997.

Zak, Omer. "Music and the Deaf." [document on-line] (28 April 1997 [cited 19 August 1997]); available at http://www.weizmann.ac.il/deaf-info/music.html; INTERNET

APPENDIX A

DESCRIPTION OF THESIS FOR QUESTIONNAIRE

See Symphony Description

What is See Symphony?

See Symphony is the automatic identification and visualization of emotions in music through computer software. The goal is to provide an additional way to enjoy music for those with hearing impairments.

How Does See Symphony Work?

See Symphony listens to music by way of CD or microphone through a computer. The music is analyzed up to 30 times a second for pitch, volume, and tempo. Based on these properties *See Symphony* determines the emotions being portrayed by the music and produces a display to the screen.

How is the Emotion of Music Displayed?

See Symphony uses colors, shapes, and movement to display the emotions of music. The colors are those of the standard color wheel: red, orange, yellow, green, blue, and purple. The default emotional category that each color is linked to is based on research, but the color-emotion relationship may be changed according to the user's preferences.
The ellipse is the basic shape used in the *See Symphony* animations. The louder the music is the larger the ellipse becomes. The reverse is also true, as the volume becomes more quiet the ellipse will shrink in size. The shape also reacts to pitch. A low pitch will cause the shape to flatten out, while a high pitch will cause the shape to tighten up.

APPENDIX B

COVER LETTER AND QUESTIONNAIRE FOR HEARING-IMPAIRED SUBJECTS IN RESEARCH STUDY

See Symphony Participant Instructions I

Thank you for participating in the *See Symphony* project.

The purpose of *See Symphony* is to provide another way to enjoy music. More specifically, it is designed to allow those with hearing impairments to more fully experience the emotions that music portrays through animation and colors.

You will be asked to complete a questionnaire. The questionnaire is used to gather some basic information about your hearing impairment (Section I) as well determining how you associate colors with emotions and feelings (Section II).

After completing Sections I and II of the questionnaire you'll be asked to watch three separate animations of musical works. The first two animations will be violin solos while the last will be a complete orchestra. The music will be playing simultaneously with the animations through speakers near the computer screen. You should be able to feel the vibrations of the music through the table where you'll be seated. You may listen to the music through headphones if you prefer.

Please focus all of your attention on the animations. If there is anything distracting you please let us know. At the end of each animation you will be asked to describe what emotions you felt were portrayed by the animation. You will also be able to add any additional comments about each animation.

When all of the animations are complete feel free to add any additional overall comments about the *See Symphony* project.

If you wish to be informed concerning further work on this project please enter your contact information on the *See Symphony* Contact Sheet.

Thank You for your help!

See Symphony Questionnaire I

Thank you for taking the time in assisting with this study. Please answer the following questions as accurately as possible. You may continue on the back if you need more space for your response.

Section I

1) Age? ______

2) What is your level of hearing impairment? (circle one):

Partial (Please answer Question 2.1 below)
Full (Skip to Question 3)

2.1) If you have partial hearing impairment, please describe (what sounds can you hear?):

____
____
____

3) Have you been hearing impaired from birth? (circle one):

YES (Skip to Question 4)
NO (Please answer Question 3.1)

3.1) At what age did you lose your hearing? ______

4) Do you use any devices to aid your hearing? (circle one):

YES (Please answer Questions 4.1 and 4.2)
NO (Skip to Question 5)

4.1) What device do you use? ______________________
4.2) In what way does it improve your hearing?

____
____

5) Do you have any experience with music (listening, playing, feeling)? (circle one):

YES (Please go to 5.1)
NO (Skip to Question 6)

5.1) Please explain your musical experience. Also include your musical preferences:

____

____

____

6) Have you been involved in any other studies involving music and hearing impairment? (circle one):

YES (Please go to 6.1)
NO (Skip to Section II)

6.1) Please explain the previous study(ies) in which you were involved:

____

____

____

____

Section II

Select the color which you feel most closely portrays the emotions/feelings in each given category. Please draw a line from a color to an emotion/feeling category to indicate your selection. Use each color only once.

COLORS	EMOTIONS/FEELINGS
Red	Exciting, Passionate, Stimulating
Orange	Lively, Energetic, Jovial
Yellow	Happy, Cheerful, Fun
Green	Refreshing, Peaceful
Blue	Subduing, Sober, Calm
Purple	Sad, Mournful, Royal

Section III

Music 1: *24 Caprices for Solo Violin, Op. 1, No. 4 in C Minor - Nicolo Paganini*
Please describe the emotions or feeling that you think the animation displayed:

Additional Comments:

Music 2: *Sonata No. 3 in C Major, Allegro Assai - J. S. Bach*
Please describe the emotions or feeling that you think the animation displayed:

Additional Comments:

Music 3: *Theme from JAWS - John Williams and the Boston Pops Orchestra*
Please describe the emotions or feeling that you think the animation displayed:

Additional Comments:

APPENDIX C

COVER LETTER AND QUESTIONNAIRE FOR HEARING SUBJECTS IN RESEARCH STUDY

See Symphony Participant Instructions II

Thank you for participating in the *See Symphony* project.

The purpose of *See Symphony* is to provide another way to enjoy music. More specifically, it is designed to allow those with hearing impairments to more fully experience the emotions that music portrays through animation and colors.

You will be asked to complete a questionnaire. The questionnaire is used to gather some basic information about you (Section I) as well determining how you associate colors with emotions and feelings (Section II).

After completing Sections I and II of the questionnaire you'll be asked to watch and listen to three separate animations of musical works. The first two animations will be violin solos while the last will be a complete orchestra. The music will be playing simultaneously with the animations through speakers near the computer screen. You may listen to the music through headphones if you prefer.

Please focus all of your attention on the animations. If there is anything distracting you please let us know. At the end of each animation you will be asked to describe what emotions you felt were portrayed by the music and how well the animations corresponded to the music. You may also add any additional comments about each animation.

When all of the animations are complete feel free to add any additional overall comments about the *See Symphony* project.

If you wish to be informed concerning further work on this project please enter your contact information on the *See Symphony* Contact Sheet.

Thank You for your help!

See Symphony Questionnaire II

Thank you for taking the time in assisting with this study. Please answer the following questions as accurately as possible. You may continue on the back if you need more space for your response.

Section I

1) Age? ______

2) Do you have any experience with music (listening, playing, etc.)? (circle one):

YES (Please go to 2.1)
NO (Skip to Question 3)

2.1) Please explain your musical experience. Also include your musical preferences:

____
____
____
____

3) Have you been involved in any other studies involving music and hearing impairment? (circle one):

YES (Please go to 3.1)
NO (Skip to Section II)

3.1) Please explain the previous study(ies) in which you were involved:

____
____
____
____

Section II

Select the color which you feel most closely portrays the emotions/feelings in each given category. Please draw a line from a color to an emotion/feeling category to indicate your selection. Use each color only once.

COLORS	EMOTIONS/FEELINGS
Red	Exciting, Passionate, Stimulating
Orange	Lively, Energetic, Jovial
Yellow	Happy, Cheerful, Fun
Green	Refreshing, Peaceful
Blue	Subduing, Sober, Calm
Purple	Sad, Mournful, Royal

Section III

Music 1: *24 Caprices for Solo Violin, Op. 1, No. 4 in C Minor - Nicolo Paganini*
Please describe the emotions or feelings that you think the **music** portrayed:

____

____

How did the animation correspond to the emotions and feelings of the music:

____

____

Additional Comments:

____

Music 2: *Sonata No. 3 in C Major, Allegro Assai - J. S. Bach*
Please describe the emotions or feelings that you think the **music** portrayed:

____

____

How did the animation correspond to the emotions and feelings of the music:

____

____

Additional Comments:

____

____

Music 3: *Theme from JAWS - John Williams and the Boston Pops Orchestra*
Please describe the emotions or feelings that you think the **music** portrayed:

____

____

How did the animation correspond to the emotions and feelings of the music:

____

____

Additional Comments:

____

____

APPENDIX D

MESSAGES FROM GROUP SUBJECTS

*Subject Position: in front of primary display, but 7-8 feet away.

From: Bob Gattis
To: John Billups
Subject: See Symphony Demo Feedback
Date: Friday, November 14, 1997 4:46 AM

Hi Jay,

Sorry this is a little late...

Your demo was excellent - I liked the simplicity of the ellipse you chose to animate the music's features. It was surprising how much information a single shape could convey. The real-time nature of the sound processing was impressive, although I would like to see you experiment with some form of signal averaging, to smooth out the visual response to the music. I found the rapid visual transitions of both color and shape somewhat distracting.

As far as visually representing emotions, I have to confess that the demo was a mixed success. For me, the rapid changes in the visual display for some music worked against creating a sustained emotional "feel". In addition, I would suggest you try some additional types of musical input for emotional content testing. Specifically, you might try organ music, such as funeral dirges, for the sad emotion and a flute solo, for a lighter, happier emotion. This would also separate the musical tonalities - pitch as well as volume. The deaf or hard of hearing person would also probably be able to sense the difference between these musical selections through the different vibrations produced.

In summary, I think you did a superb job of attacking the problem and have a great foundation for further testing and development. What are you waiting for? Get back to work and quit reading your email!

Best wishes,
Bob

Bob Gattis - Meeting the Challenge, Inc.
3630 Sinton Rd., #103
Colorado Springs, CO 80907

*Subject Position: directly in front of primary display.

From: Steve Stock
To: John Billups
Subject: Demo comments
Date: Thursday, November 13, 1997 20:36 PM

Hi Jay

This is Steve from Meeting the Challenge, with a couple of comments on your recent demo. First, if you remember, I found myself saying after the demo "It would be great to hear that without the sound."--somewhat of an oxymoron, but revealing in its own way. Secondly, it seems to me their is no end to the research and testing that could be done with your system. It would be interesting to see how consistently (and quickly) people with deafness could identify a piece of music after becoming somewhat familiar with the "screen dance" of images that your system provides. Inasmuch as hearing people enjoy listening to music, do non-hearing people enjoy watching it? Would non-hearing people discriminate between 'good' music and 'bad' music in the same way hearing people do? For that matter, does 'good', or popular music consistently remain good when transformed to the computer screen? Anyhow, good luck with the thesis, graduation, etc. I received my graduate degree from UCCS, and it was a great experience. --Steve

*Subject Position: closer to secondary display.

From: Randy Dipner
To: John Billups
Subject: See Symphony
Date: Tuesday, November 11, 1997 16:30 PM

Jay,

Thank you for the opportunity to be a part of your Masters project. We hope your interactions with MTC were as valuable to you as meeting you was to us.

I was quite impressed with the results of your work. For me the images seemed to be very much connected to the music. I could directly connect the size, proportions and roughness of the images to the volume, pitch and dissonance of the music. I did feel that the mood of the music was less well connected to the color of the images. It seems to me that mood in music is a longer duration impression built up over several bars rather than the very quick changes implied by the rapidly changing colors. I wonder whether some method of averaging over time could provide this rather smoother transition from one feeling to another. I was also more pleased with the impression of the LCD display than the monitor. The latency of the images on the LCD provided more of a clear sense of the music for me than the clean break from image to image on the CRT display. I can imagine a very impressive display with each instrument separately mic'ed and the images displayed in some form of overlapping presentation.

Congratulations on the success of your research. I hope you will stay in touch as you move forward with this project.

Please feel free to use anything I have said here at your discretion.

Sincerely,

Randy Dipner

*Subject Position: not recorded.

From: Mark Snow
To: John Billups
Subject: See Symphony test
Date: Monday, November 10, 1997 12:19 PM

Greetings Jay:

Thanks for the opportunity to take part in the review of See Symphony. It was great to see your enthusiasm and dedication toward something that will be of benefit to thousands of people.

Your demonstration reminded me of the vivid colors and sweeping melodies that make up some of the segments of "Fantasia". I think it is fair to say you have taken current technology and made it both useful and entertaining.

Best of luck in the future with See Symphony!

Mark Snow

*Subject Position: not recorded.

From: Pat Going
To: John Billups
Subject: See Symphony
Date: Monday, November 10, 1997 14:34 PM

Pat Going

Thank you, Jay, for your demonstration last week. As you know, people who are deaf or hard-of-hearing constitute almost 50% of the total number of people with disabilities in the U.S. Incorporating visual representation - like your program - into concerts, etc. will have a tremendous appeal to many people. Be sure and come back as you continue to make refinements to this ambitious and exciting project.

Patrick Going, Project Director,
Rocky Mountain ADA Technical Assistance Center.

*Subject Position: close, just to right of primary display.

From: Alan
To: John Billups
Subject: Symphony response
Date: Thursday, November 20, 1997 12:26 PM

Alan J Ocken
Meeting The Challenge, Inc.

I would like to say first of all that I truly enjoyed the presentation that was made and feel that software such as this has a place with hearing folks as well as deaf. It took me back to the days when I would stair for hours at my graphic equalizer. Walt Disney made a ton of money from Fantasia the movie. A scene in that movie had multi-colored waves that were choreographed to evoke an emotional response. This type of technology will create the ability to have real time (not choreographed) images to accompany music. The issue of changing colors and patterns at too rapid of a rate: It is a gut feeling - totally unsubstantiated - that a hearing person and more over a deaf person's brain is capable of sampling at a very rapid pace and then sub-consciously assembling these samples into an emotional response. After all is said a done, music is a language that conveys an emotional message. The Bible itself speaks about music in well over 900 separate verses. If music is a language then it must be assumed that this language may be conveyed in multiple ways. We have written text, verbal language, ASL, and Braille that convey the language we call English. Our mind must learn to assemble separate bits of information or samples and then assemble those samples in an understandable way. Stephen King, Louis Farrakhan, William Shakespeare, and Jesus all used the same set of basic tools -- languages to communicate drastically different messages. The words remained consistent, it is how those words are arranged and crafted then interpreted that solicit the desired emotion. Our incredible brains make this possible. The use of colors and shapes to convey a musical message is exciting bit of research that should be followed up on.